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ABSTRACT

A systems approach was applied to the development of a multimedia computer managed course in college physics for the U. S. Naval Academy by the New York Institute of Technology with funds provided by the U. S. Office of Education. The experience in the construction of the program is incorporated into a course development model to serve as a prototype for construction of similar programs in other hard science courses. Extensive record keeping capabilities of the program allow it to serve as a vehicle for educational research. The course is individualized; self-paced with an iterative process of successive tryouts and revisions. Each student's learning experience is individualized by offering optional routes through the learning materials using various media. Over a thousand measurable behavioral objectives were developed to completely specify the performance which the program should elicit. The media components, testing, remedial materials, and laboratories are described. (TS)

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DOCUMENTATION REPORT

SE 013 505

TECHNICAL REPORT 5.10

COURSE DEVELOPMENT

Physics Program

Submitted by the

New York Institute of Technology
Old Westbury, New York 11568

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PREFACE

The Course Development and Course Evaluation reports (TR 5.9 and 5.10) are the principal reports which describe the physics program delivered under Contract N00600-68C-0749 to the U.S. Office of Education.

Three versions of the program were developed. The initial (1968) version received a tryout at the Academy during the last part of the Fall of 1968 and during the Spring of 1969. The second (1969) version had a tryout in the Fall of 1969, and the final (1970) revised program was installed in the Fall of 1970.

The Fall 1968 materials were the first rough draft version and were used with only a few students in order to determine level of expectation, quality of materials and time requirements. The second tryout involved a considerably greater amount of material and lasted for the entire Fall 1969 semester with approximately one hundred students.

On the basis of performance and student preference data the final version of the course was derived. Major changes in course content and operation were introduced in 1970. At this time, Academy faculty had the first opportunity to develop materials according to the methods detailed in the Course Development report. The faculty materials development effort was concerned principally with adding content to the original course in order to meet new Academy curriculum requirements which expanded the basic course to two semesters.

The course as delivered is self-paced, independent study, multimedia, computer or manually managed, introductory classical physics. It can be used at the U.S. Naval Academy with any number of midshipmen or at any other institution having a need for the content contained in the objectives (as listed in TR 5.2.1 and 5.2.2).

The Course Development report, TR 5.10, sets forth the procedures for developing new courses or adding content to existing ones. Capable professionals, through the use of this model, can design and develop self-optimizing courses or segments of courses. Evaluations of developmental processes are also detailed in this report.

Summative evaluation is contained principally in Technical Report 5.9, Course Evaluation, and to a lesser extent, in TR 5.0, Statistics: 1969 Experiment. A study and evaluation of the classification of objectives is detailed in TR 5.8, Classification of Learning Objectives.

PRINCIPAL REPORTS

TR 5.10 Course Development A description and evaluation of the development procedures. Missteps and failures are documented as well as successes.

TR 5.9 Course Evaluation An examination of improvement in the revised program, and a comparison with conventional instruction.

TR 5.8 Classification of Learning Objectives Introduces and evaluates a classification hierarchy based on complexity of hard science objectives.

AUXILIARY REPORTS

TR 5.0 Statistics: 1969 Experiment A statistical analysis of data from the 1969 tryout.

TR 5.1 Course Description An overview to put the course in perspective. (Included in TR 5.10.)

TR 5.2.1 Course Objectives Each of the performance objectives is represented by a problem so that the level, scope, and assessment measures are described in unambiguous form.

TR 5.2.2 Course Structure and Sequence The topical sequence of objectives including the decision processes which led to this sequence.

TR 5.3 Test Item Bank A compilation of criterion check items and diagnostic test items identified by terminal objectives. The item bank includes multiple questions for each terminal objective and item statistics collected during the tryout conducted in the Fall of 1969.

TR 5.4a Management System Report A description of course implementation procedures recommended by the contractor and the method of presenting feedback. Record-keeping procedures and the forms on which records can be kept are described.

TR 5.5 Revision Process Documentation A description of the specific empirical revision activities, rationale for these activities, and a compilation of the data upon which revision decisions were made.

INTERIM REPORTS

The interim reports submitted in 1969 describe the objective considerations and rationale for the Fall 1969 tryout. These reports include:

TR 4.7 Rationale for Sequencing Objectives
TR 4.7.1 Evaluation and Validation Design
TR 4.7.2 The Validation Process
TR 4.9 Design for Selection of Strategies and Media
TR 4.3 Course Revision and Restructure
TR 4.12 Weekly Course Segment Documentation, Weeks A through O.

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INTRODUCTION

COURSE DESCRIPTION

A systems approach was applied to the development of a multimedia computer managed course in college physics for the U.S. Naval Academy.

Student Population

The students are Academy midshipmen who are generally engineering and applied science majors. Their college experience includes one year of chemistry and introductory calculus. Clearly, this is a highly select and well motivated student population. The following is a brief description of the course.

Goals

Several purposes are served by the program's development and operation. The Academy is provided with a cost-effective physics course designed with the most modern educational technology. The experience garnered in the construction of the program is incorporated into a course development model to serve as a prototype for construction of similar programs in other hard science courses. Extensive record keeping capabilities of the program allow it to serve as a vehicle for educational research.

Characteristics

The course is individualized, self-paced, and self-healing. By offering media optional routes through the learning materials, each student's learning experience is individualized. A student can use any learning materials on an individual basis and, within practical limits, at any time which is convenient for him. Likewise, within broad time constraints, the student can progress through these materials at his own pace.

The self-healing aspect of the program pertains to learning materials and processes. These are improved by an iterative process of successive tryouts and revisions. In this way, the program undergoes an empirical optimization procedure.

Content and Level

The content and level of the course is generally described as introductory college physics with calculus for sophomore students of science and engineering.

Most standard topics in introductory classical physics are included in the two semester course: mechanics, wave phenomena, electricity, magnetism, and optics. One unusual feature is the omission of heat and thermodynamics in favor of more intensive developments in mechanics and optics to suit the Academy's particular needs.

Systems Approach

Optimization of the program must be attained empirically, since no satisfactory predictive theory of educational psychology is known. This situation is well suited to a systems approach when the output of the system can be fed back to modify the system input.

Behavioral Objectives

This approach requires that the course objectives are clearly defined and measurable so that the output of the system is quantitative.

Consequently, over a thousand measurable behavioral objectives (MBOs) were developed to completely specify the performance which the program should elicit. MBOs fall into two categories: terminal objectives (TOs) which describe the desired final student behavior, and the subordinate enabling objectives (EOs) which are steps toward the terminal behavior.

The TOs constitute a complete description of course content and are represented in the course by central *core* problems. When a student can answer a core problem correctly, he is said to have achieved that TO. In this way a student knows exactly what is expected of him as to content and level of proficiency.

When a student cannot answer a core problem after a single exposure, he can execute subordinate *enabling* problems which correspond to the EOs. At the end of an enabling sequence, the student is presented with another version of the core problem to check his achievement of the TO. All these problems are contained in the *Problem and Solution Book* volumes.

Media Components

Videotape presentations are available for forty-nine topics. These tapes average about fifteen minutes apiece. Illustrated texts and talking books (taped voice-over illustrations in book form) are available with essentially the same information content as the videotapes. (Computer-assisted instruction (CAI) was initially included as a parallel path for topics in mechanics, primarily to be compared with the other options for cost effectiveness, and was deleted as a learning option in the final revision.) Conventional physics texts are also included among the available learning materials.

Testing

Each student is provided with a *study guide* which directs him through the problem books and various media assignments. When the student completes a specified assignment (roughly approximated by a chapter in Halliday and Resnick), he schedules a *progress check* (test) on the material. This criterion check does not influence his grade but is used for management and remediation purposes. Grades are determined by quarterly tests and final examinations for each semester.

Remedials

The most extensively used remedial material is that which provides immediate feedback to the student as he progresses through the learning materials. For every problem answered erroneously, a correct solution is immediately available. Minor remediation is accomplished by distributing a *remedial sheet* associated with each problem missed on the progress check. These sheets have a statement of the appropriate core problem together with references to pertinent auxiliary material. More serious remediation is provided by individual tutorial sessions with a professor.

Laboratories

The laboratories have as their objectives the measurement of fundamental physical quantities, including the processing and recording of these data with an error analysis. An innovative aspect of the data analysis is that a dialogue may be established between the student and the computer which would culminate in the student's achievement of the objective. This computer dialogue laboratory format is not an essential element of the multimedia learning materials, and in the current implementation the Navy Physics staff is using a conventional laboratory experience for the self-paced course.

THE COURSE DEVELOPMENT EFFORT

The course development process was seen at the outset as the construction of a system which would provide feedback for iterative revisions. Subject specialists began with essentially the same content as the traditional introductory physics course; through a refinement process of testing, decision making, and alteration, course designers expected that a more efficacious product would evolve. The actual task was more extensive than this original conception.

The first hint of a fundamental difficulty came during the original development of MBO lists. The writers intended to fractionate terminal objectives into their most elemental steps. The testing of every item, however, would far exceed any reasonable allocation of study time. Reduction to the smallest possible steps thus had to be rejected on purely pragmatic grounds--there was simply too much material for that approach.

A general philosophy was adopted for course development called the *lean approach*, whereby learning packages were constructed with the fewest possible embellishments which would meet the stated objectives. Data from subsequent tryouts would then identify the weak areas, and revision would supply the necessary additional instruction and refinement. This approach has several virtues: it is economical because superfluous material is not developed, it is an aid to revision analysis because trouble spots are most easily detected in a spare format, and it allows for maximal improvement in the most troublesome areas while it avoids excessive and tedious development in areas of high performance.

This lean approach was invoked to resolve the question of how small the enabling steps should be for a given terminal objective. Each terminal objective was therefore supported by a minimum number of enabling objectives, the basic steps in reaching the terminal objectives. These enabling objectives may require one or more minute steps for their own achievement. Terminal objectives singled out due to poor performance would have their enabling objectives more finely divided.

Although 1968 final exam performance of the students in the physics program compared well with the students in the conventional course, criterion based performance was disappointing. Since the weakness seemed rather evenly distributed over most of the topic areas, it was reasoned that a uniform expansion of enabling objectives was the appropriate tonic. Enabling problems were increased from an average of eleven to twenty-four per segment. Earlier qualms of course developers were forgotten as the systems approach crank was turned and the conclusion was reached that "more is better" for all the required instructional materials.

Again in 1969 the performance of students in the physics program compared well with the conventional group on the final examination. But this time, in spite of the refinements and additional enabling problems and instructional packages, the program met with near disaster. Early in the semester a group of midshipmen complained that the course was excessively difficult, and requested to be removed from the program. Only a large scale shifting of problems to "enrichment" and optional status saved the project.

The principal problem was clearly not one of refinement. Under the scrutiny of continual testing it became manifest that linear instruction for all objectives was far too demanding of students' time. Indeed, the corrollary followed that conventional physics courses are also too crowded for the allotted credit and time--the difficulty is simply not perceived by limited monitoring. Thus evaluators arrived at the conclusion long known to most students: the hard sciences are different and more difficult than other subjects.

Perhaps part of the reason lies in the observation that the introductory texts in hard sciences easily contain as much textual information as a standard textbook in world history--but the acquisition of all this factual knowledge is only a beginning. Hard sciences are problem oriented and demand the development of problem solving *skills*. An adolescent who religiously studies *Hot Rod* magazine still must learn to drive; the student scientist may learn every physical fact in his textbook, but he will surely fail his examinations without having practiced problem solving.

The excessive time required for completing the course work was the greatest single difficulty encountered in the development of the physics program. The trouble was not clearly appreciated until the 1970 revision. It was then obvious that the importance of this factor had been unanticipated and was only minimally controlled and recorded. Course designers were in the embarrassing position of having prepared for a refinement process when a major reconstruction was required.

In addition to the factor of student time in study, two other quantities appear to have this important *macrovariable* status: student motivation and course level. Motivation is characteristically high at the Naval Academy, and thus did not present any special problem for the physics project. The program evaluators suspect that motivation would be a greater problem at the compulsory education level. Nevertheless, they believe that putting the course on a self-paced basis is conducive to student motivation because there are rewards intrinsic in such a system; the students may advance at their own rates with the satisfaction of knowing how well they are succeeding as they progress.

The notion of course level is subject to considerable ambiguity in the hard sciences as stated in common curriculum form. A curriculum for a high school physics course might be indistinguishable from that of an introductory college course as judged by chapter and section headings. The process of labeling subject matter is insufficient to describe the intended depth of the course.

This problem has been recognized for some time, and has been approached by stating objectives behaviorally, usually in verbal form. Since the hard sciences are problem solving oriented, we specified level in problem form; that is, all objectives were defined by sample problems. In this way, the student knows immediately what behavior is expected of him on a criterion test.

A distinction has been drawn between macrovariables and *microvariables*, which pertain to the small adjustments of content, presentation, and sequencing. In the hard sciences these microvariables are far more precisely defined than in other disciplines.

In order to relieve the demand on students' study time, the possibility of reducing course content was considered. One of the contractual requirements, however, was to develop materials corresponding to the conventional S211 course. This meant that *all* students were required to study the same topics and take the same final exam. The program developers were responsible, then, for maintaining all the topics in the curriculum, although in conventional courses instructors are at liberty to adjust topic coverage through omission and abridgment. To maintain the feedback requirement for course revision, it was required that students pass through all the material.

To mitigate the problem of excessive demands on students, a new format was constructed. The first objective to be met in any topic is a *core* problem--a terminal objective in problem form. A completely detailed solution follows immediately. These provide the student with the clearest statement of the performance required and provide an excellent advance organizer. This format allows a direct assault on the terminal objective so that detailed enabling objectives may not be necessary. Another core problem, closely parallel to the original, is presented at the end of an enabling sequence. The forward branching economizes the student's time and avoids his laboring unnecessarily over more problems.

Our solution, then, is to provide the student with a terminal objective and to show him the correct way to achieve it. The student thereby focuses on the essentials he needs to meet the objective. If this is sufficient, he need not expend valuable time and effort on this objective, but may proceed immediately to the next core problem.

COURSE OBJECTIVES

SELECTING COURSE CONTENT

The first step in course development is to prepare a framework of general topic headings which loosely define the course content. This is easily accomplished in the hard sciences by selecting chapter and section headings from some standard textbook. The edition of the textbook should be at least two years old to insure that the authors have had a chance to correct the most obvious deficiencies of earlier printings.

Instructors who will administer the course should be included in the selection procedures whenever possible. Our experience has been that instructors exhibit considerably more drive and interest in the program when they have participated in the development phase. The chapter and section headings should be arrived at by a consensus or some compromise. Autocratic rulings by a technical director or department chairman, however wise or correct, should be avoided. It is likely that in order to satisfy everyone, more topical material will be included than might be chosen by any one instructor.

The committee of instructors must bear in mind the preparedness of the incoming students and the role of the program as prerequisite to other studies. Naturally, any constraints on the subject matter must be considered at this time. The subject matter areas in the physics program, for example, were dictated by specific needs of the Naval Academy, and include most fundamental topics in basic mechanics, and basic electricity and magnetism.

Stated broadly, the mechanics topics are: kinematics, vector algebra, Newton's laws of motion, gravitation, work, conservation of energy, impulse, conservation of linear momentum, and collisions. The electricity and magnetism topics include: charge and Coulomb's law, the electric field, Gauss's law, electric potential, capacitors and dielectrics, resistance, currents, Ohm's law, Kirchhoff's rules, magnetic field, Ampere's law, Faraday's law, Lenz's law, law of Biot-Savart, and inductance.

Textbook publishers usually identify course material as "hard" or "soft"; hard refers to those for which a well defined course content has evolved. Soft subjects are more amorphous, and one text may differ from another even though they are directed to the same course and student population. The physical sciences clearly fall into the hard category.

Any significant variations from the highly structured course content is likely to meet with considerable opposition from some professors, especially when they did not participate in making the change. An unorthodox development in symmetry, for example, had to be deleted after the first tryout due to the course instructors' dissatisfaction. Course developers, however, contended that students would find it interesting and that it would greatly simplify the approach to conservation of energy and momentum. We suggest that well established topic headings in standard texts be taken as the base from which to work. Departures should be promoted by their adherents to the other instructors before course material is developed and forced upon unreceptive faculty.

Our remarks about the well established topical content of hard science courses have to be tempered somewhat for less evolved sciences such as molecular biology. In such cases the broad course content outline may have to be established with little or no reliance on a standard text, and compromise will have to play a larger role.

Discriminating between "subtopics" and "major topics" must be left to the course developers. We had no difficulty in making such assignments, and we assume that it is equally simple in the other sciences. Most of the major topics correspond to chapter headings and subtopics correspond to section headings in a conventional textbook. For example, under the following listing:

COLLISIONS	Major topic (chapter heading)
Definition of Impulse	Subtopics (section headings)
Impulse and Momentum	
Collisions in One Dimension	
Collisions in Two Dimensions	

The topic headings are hardly likely to be understood by a nonscientist. This is unimportant since course content listings are used for information only by course writers and instructors. These specialists generally have an excellent idea, due to precedent and experience, of the content implied by such cryptic topic labels.

When these lists are written and agreed upon, they must be reproduced in sufficient quantity to serve as working check lists for all the course developers.

WRITING COURSE OBJECTIVES

The need for stating objectives has been emphasized over the past years and now enjoys widespread acceptance. Attempts at specifying performance have resulted in different classification schemes, all with the intention of clarifying for instructors, course developers, and students what will be accepted as an indication that a student has learned. Because we cannot see learning directly, we must base our analysis of learning on more concrete evidence; we take as our evidence a modification of behavior, a change that can be demonstrated and measured.

After determining the general course outline for the physics program, we began writing Measurable Behavioral Objectives (MBOs). To assist the course writers in listing MBOs that were behavioral, we prepared sample items and lists of action verbs. Unfortunately, we later realized that using words such as *define, convert, perform, apply, select, state, indicate, write,* does not insure specific measurable behavior.

For example, some of our earliest efforts produced these objectives:

Define a derived quantity as used in physics.

Convert length in one metric unit to length in any other metric unit.

Describe qualitatively the operation of a quartz crystal clock and give the order of magnitude of its precision.

Indicate understanding of the procedure used to adjust local clocks by means of time signals from WWV.

Write any given number in scientific notation.

Apply area and volume formulae to the solution of problems.

Clearly they require action, but are not precise, do not specify the conditions under which competence must be demonstrated, and do not indicate degree of competency to be achieved.

We grouped the 3000 MBOs we prepared into Terminal (TO) and Enabling (EO) objectives, and defined TOs as the desired final behaviors. The EOs, the more specific smaller blocks leading toward the TOs, represent the transitional type of skill or knowledge which is believed to be a precondition for success on the TO. They are not all necessarily of equal importance or of equal difficulty to attain, and they may or may not build upon each other; it is sufficient only that they facilitate the mastery of their associated TOs.

This procedure of identifying objectives as terminal, or enabling, or interim, etc., is often time consuming and confusing, since TOs themselves can be EOs to still more complex TOs. Grouping them in this way, however, did provide us with a method of reviewing our lists and organizing the material efficiently. It revealed those EOs which were irrelevant to the TO and those which were redundant; for example, "Convert units of ft/min to ft/sec" and "Convert units of meters/min to meters/sec" do not require different behavior for their execution. In addition, by ordering objectives in this way, we could more easily spot omissions and prune those objectives which were of purely cultural orientation, allowing for more concentration on difficult or more important objectives.

The revised lists, reflecting a consensus reached through joint sessions with the Academy and both centers of NYIT, directed the modification effort of our course materials.

We found, through running our course, that requirements for management and revision were best satisfied by casting the objectives into the form of a representative test question. Our verbal statements of objectives, and their lack of precision, had resulted in a lack of clarity. Students were not able to assess the objective's level and scope, and so were not certain exactly what was expected of them. Professors with little specific classroom experience, regardless of their subject matter expertise, could not be sure to what extent any content was to be covered. Although there was professorial consensus on a list of objectives, there was little agreement on whether the objectives were achieved: evaluation of student progress was less than standardized.

Use of verbal objectives revealed another more serious, though less obvious, hazard. Enabling objectives are clearly discerned by the course instructor or designer only when he executes the behavior called for in the Terminal Objective. Each necessary step toward terminal behavior is then, by definition, an Enabling Objective. When a Terminal Objective is "fuzzy" the requisite steps for its achievement are even less clear. Our experience has been that this situation leads to poor ordering of Enabling Objectives under a Terminal Objective, a number of redundant Enabling Objectives, and a few omissions of Enabling Objectives.

We reformulated the objectives into problem form to eliminate these difficulties. With a precise problem to represent a Terminal Objective, any subject matter expert can perform the steps for its solution and identify the individual steps as Enabling Objectives. Moreover, specifying objectives in problem form indicates to students what behavior will be considered acceptable and under what constraints their behavior must be evidenced.

For the specifics of problem construction, see the section on "Test Items."

Core Problem Development

Core problems are generated from the course content list. All the subtopics under a major topic heading should be undertaken by the same writer (or pair of writers) so that connectedness and uniformity can be assured. Otherwise there is a danger of overlap or omission of essential material between adjacent subtopics. Furthermore, a single writer can often introduce a connecting theme throughout a major topic; it may take the form of a familiar physical situation recurring with embellishments, or a sequence of problems addressing entirely dissimilar situations but having the same analytical solution.

In developing core problems, the writer should be guided by the following rule: *Write the test problem which is the best measure of a student's achievement in the given subtopic.* By "best measure" we mean the appropriate scope and level of the test question as well as content. The ideal being sought here is the perfect examination question; one which, when successfully solved, indicates that the student has mastered the subtopic within the course structure.

It is to be expected that more than one problem will often be needed to cover a given subtopic. A good rule-of-thumb, however, is when more than one set of problems satisfy your requirements equally well, choose the set which places the least burden on the student. When one of the objectives is a synthesis of different (new) elements, we found it best to write core problems for each of the elements and for their synthesis as well.

A good deal of decision making is involved in arriving at a set of core problems. As an example, consider writing core problems for the subtopic *Collisions in One Dimension*. Several possibilities immediately occur to someone who wants to exhaustively test this topic. Collisions can be elastic (energy conserving) or inelastic, and various degrees of inelasticity can exist. In the most general one-dimensional collision between two bodies, both objects are moving (in the laboratory frame) when they suffer an inelastic collision. The final products of the collision are moving fragments of various masses. A collision of such generality is not addressed in this course.

The actual core problems which were believed appropriate to the course pertain to totally inelastic or totally elastic collisions where one of the objects is originally at rest:

1. A railroad car of mass 1000 kg is rolling down a track at 3 m/sec. It strikes a stationary car of mass 2000 kg. If the two cars couple together, what is the speed of the combination immediately after the collision?

2. In a one-dimensional elastic collision between two objects, mass m_2 is initially at rest. If u_1 = 1 km/sec, and $m_1 = 2m_2$, what is the final velocity of m_1?

3. A 1/2-ounce bullet traveling horizontally with a muzzle speed of 1500 ft/sec strikes a 5-pound block suspended from a fixed point with 5-foot, massless, inextensible cord. If the bullet remains embedded in the block, how high does the block rise? (Neglect air resistance.)

Problems 1 and 3 overlap in that they both treat collisions with coupling. However, problem 3 forces a discrimination to be made as to the circumstances under which mechanical energy and momentum are conserved. The physics of problem 1 is entirely contained within problem 3--the "new" objective contained in 3 is a synthesis of two concepts.

Course writers will usually have considerable experience in writing test questions; some elements of constructing problems are presented in the Test Items section. When a writer has completed a set of core problems, he should submit them to review by the same people who decided on course content. It should be expected that some problems will be added and some omitted.

CLASSIFYING LEARNING OBJECTIVES

Writing learning objectives for highly quantitative hard science courses requires careful specification of an elusive measure of level. For example, high school and college physics courses may cover essentially the same topical material, but with a profound difference in requirements and expected performance.

In order to categorize level in a measurable way, we attempted to develop a classification of learning objectives based on a nonarbitrary measure of complexity. Basically our measure of complexity is the number of algebraic equations required for the solution of the problem. This measure was found to be a good organizer and predictor of student performance, and has important advantages over a classification based on student difficulty.

Complexity is a nonarbitrary objective standard. It is a quality inherent in the task. Depending upon one's qualifications, it may be easy or not to achieve. In either case, complexity level can be determined in the absence of performance measures and does not require knowledge of preceding learning experience.

Difficulty, on the other hand, is both a more relative and more subjective measure. It is often determined by professorial experience with prior student performance on similar items, or by analysis of student performance, often long after it would be useful for formative evaluation.

The use of complexity has been found to be a useful predictor of problem difficulty (see TR 5.8). Since a measurable objective must specify performance, and performance is highly dependent upon complexity, it follows that complexity should be specified for hard science objectives. Even if objectives are stated in problem form, the complexity category of the problem should be known in order that variations of the problem (for use on a final exam, or for comparison purposes) can have equivalent complexity.

The classification by complexity is a useful systematizing agent. As a result of our investigations, we concluded that enabling objectives should not be more complex than the related terminal objective. EOs should facilitate success on the terminal objective: as the complexity of an EO increases, it is likely to produce a decrease in performance.

Our original classification system (see attached sample), based on Bloom's taxonomy, was found to be inappropriate for one or more reasons: too general, covering more kinds of behavior than were apparent or necessary to test in a physics problem-solving course; too ambiguously or nonobjectively defined, requiring suppositions about internal thought processes or arbitrary assignment to subclassifications; too history dependent, requiring previous learning experiences as a base. For these reasons it was decided to adopt an objective measure, problem complexity, for categorization purposes.

For the physics project, three categories of objectives were identified, and a catch-all gray category was invented. They are listed in order of increasing complexity.

(1) Zero Step Problems: Those questions which do not require any mathematical manipulation. Recall of a fact or definition, or the recognition of an object, fact, or definition fall into this category. Even difficult conceptual problems or associations are categorized as zero step questions whenever there are no algebraic steps involved. All

29 QUESTION CATEGORIES

29.1 Purpose - The structure of question categories has been erected to provide another meaningful source of input for computer data analysis and management. The plan calls for the assignment of all questions used in the course (diagnostic, criterion, and administrative) to specific educational categories as presented below. It is anticipated that this system will, by analysis of individual student performance, yield information which can pinpoint weaknesses in the student's thought processes, and thus provide direction for the remedial work.

29.2 Nature of the Category Structure - Study of the list of categories indicates that they compose a hierarchy of performance levels in which the capabilities at the higher levels rest upon those at the lower levels. Hence, the assignment of a question to a category will be based upon the highest level into which it can be placed.

29.3 List of Categories (From lowest to highest level).

Level 1:	RR	Recall and Recognition Facts, theories, laws and principles.
	BM	Basic Mathematical Skills Basic operations; one-step translations.
Level 2:	AN	Analysis Identification of elements; identification of relationships among elements; reordering and rearrangement of elements for required operations.
Level 3:	CN	Comprehension Recasting of elements to meet specific needs; translation of elements into different terms as required; interpretation of relationships among elements.
Level 4:	SY	Synthesis Implications, consequences, corollaries; solution of verbal problems; explanations of events and phenomena; derivations; formulation of hypotheses; prediction.
Level 5:	MR	Mathematical Reasoning Links between synthesized groups; sequencing groups for assembly into a comprehensive whole; multistep problem-solving.

word problems; that is, problems which are nonnumerical and nonsymbolic, are zero step problems.

(2) One Step Problems: Those problems which require the solution of one algebraic equation for one unknown, or a single calculus operation (differential or integration).

(3) Multiple Step Problems: All problems which require the solution of *more than* one algebraic equation, or more than one calculus operation.

Some examples follow:

Zero Step

At time $t = 0$, a puck is observed to move on a frictionless horizontal table with a speed of 40 ft/sec. After two seconds the speed of the puck is:

One Step

A constant force of magnitude 100 lb is required to move a block along a horizontal floor with constant speed of 4 ft/sec. The force is directed along the motion of the block. Calculate the power delivered by this force.

Multiple Step

A section of level roadway has a radius of curvature of 100 m and is expected to handle traffic at 10 m/sec. What minimum coefficient of friction prevents skids at this speed?

For more examples, see Appendices A, B, and C in TR 5.8.

We do not distinguish between two, three, or more step problems, since we can analyze the number of steps only in the intended behavior not the actual behavior. By eliminating the distinction between, say, two and three step problems, we minimize this difference between intended and actual behavior.

In addition, when more than a single operation (step) is required to solve a problem, even experts frequently disagree as to the "best" way to solve it and the number of steps required. Clearly, ambiguities in the step counting process are much more likely to occur in multiple step problems.

A fourth catch-all category included all problems which were judged not valid or which did not fall precisely into one of the three categories. Problems which had errors, insufficient information, or ambiguities were relegated to this category, as were many graphical problems which require geometrical steps rather than algebraic steps. A majority of problems lacking clear definition required simple arithmetic operations; we did not want to equate trivial arithmetic computations with algebraic steps.

Of course, all the valid problems can still be assigned to categories by making the above definitions more exhaustive and detailed.

A much more detailed description and discussion of the classification hierarchy is contained in TR 5.8.

SEQUENCING SUBJECT MATTER

The sequencing for a majority of topics in hard science are dictated by the fact that the concepts or techniques contained in one topic are often prerequisite to the treatment of a second topic. Terminal objectives of an earlier topic are prerequisite to succeeding topics. We will refer to those subject matter sequences which are mandated by this condition as "subject matter constrained sequences" (SMCS). Broad SMCS for the physics program are shown in the accompanying diagram. The topics represented, recommended for inclusion by the Academy staff, are those included in the conventional S211 course outline.

The remaining ordering of the material (within the constraints imposed by the subject matter) is established according to the criteria of "inclusion" and student difficulty. The inclusion criterion requires that when Topic B has most of the terminal objectives of Topic A as enabling objectives, then Topic B must immediately follow Topic A. This criterion receives the highest priority in subject matter sequencing, because evidence indicates that forgetting is a function of intervening learning rather than a function of elapsed time and immediate use of prior terminal objectives tends to reinforce them.

The following are sequences established by the inclusion criterion in the physics course:

Kinematics → Relative motion

Work and energy → Potential energy and conservation of energy

Conservation of momentum → Collisions

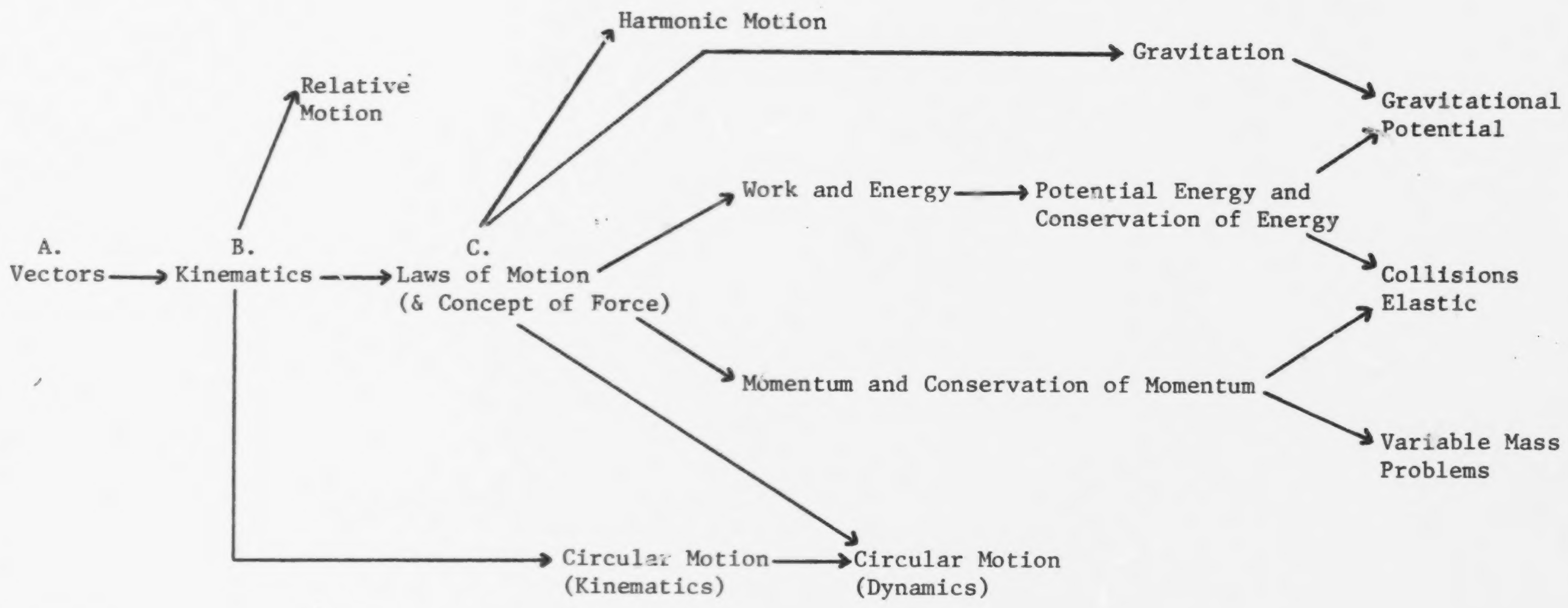
Circular motion (kinematics) → Circular motion (dynamics)

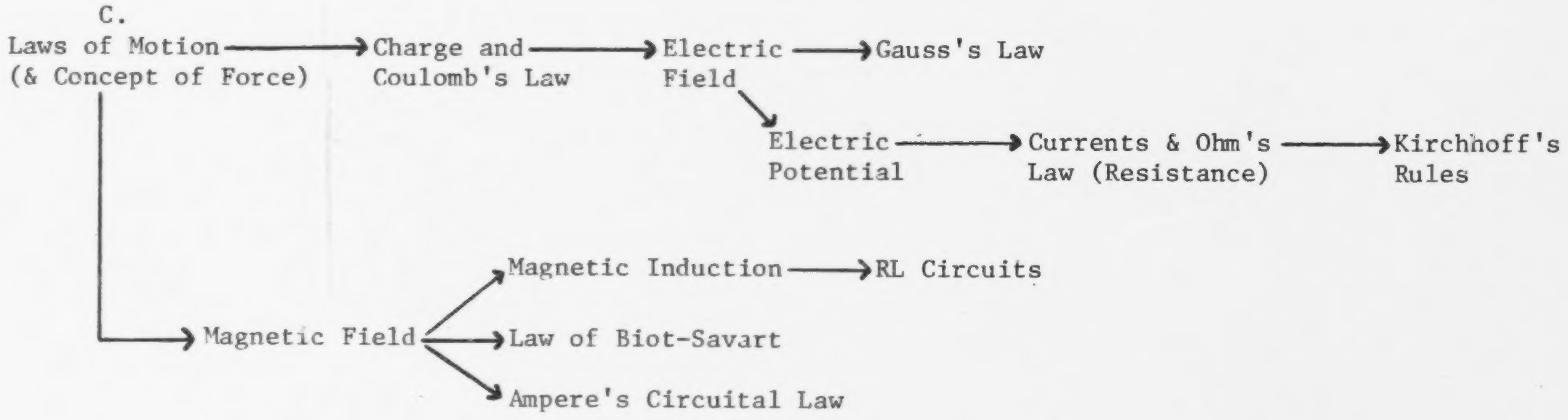
Charge and Coulomb's law → Electric field → Gauss's law

Currents and Ohm's law → Kirchhoff's rules

Student difficulty is employed as a sequencing criterion so that those topics which, in the experience of the teaching physicists, are most difficult for students are placed nearest the end of the course. This rule is based upon the assumption that a student gains maturity (facility in mathematical manipulations and rapid recognition of the principles and techniques involved) and sophistication (a backlog of concepts to rely upon) as the course progresses. Since new material should be less difficult for the more mature and sophisticated physics student, the difficult topics should be put toward the end of a sequence.

The student difficulty criterion is sufficient to dictate the remaining topic sequencing to be contained in the Problem and Solution Books.


A.
Vectors
B.
Kinematics
Relative Motion
C.
Laws of Motion
(& Concept of Force)
Harmonic Motion
Gravitation
Gravitational Potential
Work and Energy
Potential Energy and Conservation of Energy
Collisions Elastic
Momentum and Conservation of Momentum
Variable Mass Problems
Circular Motion (Kinematics)
Circular Motion (Dynamics)


C.
Laws of Motion
(& Concept of Force)
Charge and Coulomb's Law
Electric Field
Gauss's Law
Electric Potential
Currents & Ohm's Law (Resistance)
Kirchhoff's Rules
Magnetic Field
Magnetic Induction
RL Circuits
Law of Biot-Savart
Ampere's Circuital Law

MATERIALS

INFORMATION PANELS

Information Panels usually provide an overview for the student, or supplement information offered elsewhere. They direct attention to the theory required for the core problem solution. Information Panels always describe the core objectives in a form which is comprehensible to the student (see attached sample).

Information panels also serve to present supplementary topics chosen on several bases. "Trouble topics," those concepts which students inevitably find difficult to attain, can be identified by experienced instructors and examined more fully here than in a usual presentation. In addition, Information Panels provide an excellent opportunity for the professor to detail a different approach to a conventional topic, or relate relevant experience. In early versions of the physics program, these functions were served by "Supplementary Notes" distributed throughout the problem books.

The Supplementary Notes had the character of informal discussions about recondite points, often clarifying details and showing explicit examples. (A sample of Supplementary Notes is attached.) These were well received by students, so we attempted to maintain the same informal style in the Information Panels.

The need for presenting learning objectives in a simplified form which is clear and comprehensible to students was recognized in the earlier versions.

The students were given statements of the objectives at the beginning of each week of the course. These objectives were the same descriptions that were initially developed by the course designers for

INFORMATION PANEL

Work Done by a Constant Force

OBJECTIVE

To calculate the work done by a constant force, that is, a force which varies neither in magnitude nor direction.

In the simplest situation, where the force applied to a body is constant in both direction and magnitude and where the resulting motion occurs in a straight line, we define work as the product of the magnitude of the force and the displacement of the particle on which the force acts.

Since force and displacement are both vectors, care must be taken to use a consistent system of symbols. In our work we will continue to use $\vec{r}$ for the position vector. Displacement will be designated by $\vec{s}$ so that a particle moving from position $\vec{r}_1$ to $\vec{r}_2$ will undergo a displacement of $\Delta\vec{r} \equiv \vec{s} = \vec{r}_2 - \vec{r}_1$. Thus, with this convention, $d\vec{s} \equiv d\vec{r}$ and the two differentials may be used interchangeably although $d\vec{s}$ will be the preferred form.

The work W done by a constant force $\vec{F}$ acting on a body which moves through a displacement $\vec{s}$ is $W = \vec{F}\cdot\vec{s} = Fs\cos\theta$ in which θ is the angle between the two vectors.

If we designate the component of the force in the s-direction as F_s, then

$$F_s = F\cos\theta$$

and so

$$W = F_s s$$

In working through the problems dealing with the work done by a constant force, you will be expected to

(a) justify the conclusion that the work done by centripetal force on a particle moving uniformly in a circle is zero;

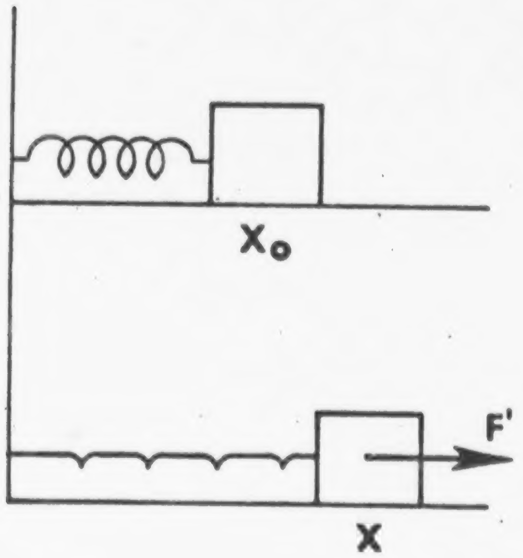
(b) calculate the work done on a given mass when moved up an incline by a given distance;

(c) find the work done on a given mass when lifted vertically over a given distance.

a. Supplementary Notes

In the problems we have dealt with in this segment thus far, the "work done" was given or found to be a positive quantity. However, although work is a scalar quantity, it is convenient to assign a sign to it. This sign indicates which body does the work. If, for example, we are trying to find the work done by body A on body B and it happens that body B is actually doing work on body A, then the work W_{AB} will be a negative quantity. By convention the work done by a physical "system" on its environment is taken to be positive. If the work comes out negative, then we know it is the environment that does work on the system under consideration. In the following question the "system" will consist of a spring resting on a smooth table. One end of the spring will be fixed. The convenience of the convention on the sign of the work done will become apparent from this question.

A spring is said to obey Hooke's law if the force necessary to stretch (or compress) the spring is directly proportional to the degree of stretching (compression). Within limits, most springs obey Hooke's law.



If the equilibrium position of the free end of a spring is $\vec{x}_o$, the force $\vec{F}'$ necessary to stretch the spring to a new position $\vec{x}$ is given by $\vec{F}' = k(\vec{x}-\vec{x}_o)$, where k is the force constant of the spring. Sticking to our convention, we talk of the force the spring applies to its environment. From Newton's third law this force is $\vec{F} = -\vec{F}' = -k(\vec{x}_o-\vec{x})$, or, written in scalar form, $F = -k(x-x_o)$.

communication with subject matter experts, Academy faculty, and other project staff. The objectives were *not* designed specifically to communicate the intent of the instruction to the student. When objectives are frequently incomprehensible to the student until *after* he has achieved them, students tend to receive far less information from the objectives than is desirable. The purpose of giving a student the objectives is to provide him with a concrete, identifiable goal, and to give him some basis for self-evaluation of progress toward that goal in terms of his own performance capability. If the objectives do not serve that purpose, a central component of the system is missing; if the students recognize the deficiency, they tend to not bother to read the objectives. A major rewriting of objectives was called for to produce a set of written descriptions that would be comprehensible to the students prior to their contact with the study materials, and usable by the students as a progress evaluation guide.

The usefulness of the early student oriented objectives was obviated, then, by several faults:

a) The statements of objectives were listed on a separate page (see the sample of Phase II descriptive objectives). In order to be most effective, these objectives should appear just before the student encounters the associated learning material.

b) The terms used in the descriptions were not previously defined. Thus, "work," "power," "kinetic energy," and "work-energy theorem" were not yet defined at the time a student encountered the instructional objectives.

c) The objectives were not stated in precise behavioral terms. It is clear that a student could not really tell when he was

SEGMENT SEVEN

ASSIGNMENTS

Reading		*Homework*
HR	Chapter 7*	HR 7-8
SW	6-1, 7	
SZ	7-1, 2, 3, 9, 10	
AB	6-1, 2, 3, 5, 6, 7; 27-1, 2, 3	

INSTRUCTIONAL OBJECTIVES

Upon completion of this segment you should be able to

(1) answer fundamental questions and solve problems pertaining to the work done by a constant, or displacement-dependent force (graphically and analytically,

(2) solve problems involving the power delivered by a mechanical system, and

(3) solve problems involing the kinetic energy of a system and the use of the work-energy theorem.

Please turn to page 5.

---

* Indicates reading of prime importance.

"...able to answer fundamental questions and solve problems pertaining to the work done by a constant, or displacement-dependent force." Compare this with the more behavioral statements which succeed it in an Information Panel: "In working through the problems dealing with the work done by a constant force, you will be expected to

1. justify the conclusion that the work done by centripetal force on a particle moving uniformly in a circle is zero;
2. calculate the work done on a given mass when moved up an incline by a given distance;
3. find the work done on a given mass when lifted vertically over a given distance.

PROBLEM AND SOLUTION BOOKS

The Problem and Solution Books, in their present form, contain Information Panels, core and enabling problems, and detailed solutions for all problems. We will discuss the precursors of the Problem and Solution Books and indicate the major steps in evolving to the current format. Hopefully, this treatment will help others avoid our earlier missteps.

Our first version of the P&S Book was a branched program which included all instructions to manage students through the course materials. Reading assignments, supplementary notes, directions to audiovisual materials, problems, and remedial frames were all contained in the original sixteen volumes. Three features were to undergo considerable change: the remedial function, the problem format, and the management function.

Remediation had a central role in the early P&S Books (see also the section on Remediation). The problem statements were all in multiple step format; when a student selected the correct answer on an auxiliary answering device, a check (✓) was displayed indicating that he should proceed to the next problem (see sample page of original problem book). When an incorrect distractor was selected, a page number was displayed indicating the location of remedial information. On occasion, the distractor was sufficiently inappropriate to warrant the display of a cross (×) indicating "try again."

This remedial emphasis arose from an assumption that a substantial

Sample Page of Original Problem Book

(22.1) 1-1-1.0

(22.2) Reading: HR 1-1, 1-2.

(22.3) Supplementary notes: The story of the growth of measuring units is a fascinating one. From it, one gets an insight into the ways that man has devised to overcome the problems he faced when he began to acquire property, indulge in barter, and exchange services. Audio-visual number 1 (AV 1) is concerned with this narrative.

(22.4) AV: 1, The Growth of Measuring Units.

(22.5) AV Data: None

(22.6) QUESTIONS AND PROBLEMS

(22.7) 1. This question is presented in AV 1.

X A Unavailability of the measuring device.
✓ B Variability of the standard of measurement.
X C Inconvenience of the selected unit.
X D Absence of multiples and submultiples of the chosen units.

(22.8) 2. Why is length considered a fundamental quantit

✓ A Its defining operations are not based on physical quantities.
1.1 B It is easy to measure
1.2 C Its standard unit may be subdivided into smaller standard units.

(22.9) 3. Which one of the following is a derived quantit

1.3 A Time.
1.4 B Length.
1.5 C Area

(22.10) 4. Which one of the following measures the same fundamental quantity as the cubit?

X A acre
X B gallon
2.0 C rod
1.6 D minute

fraction of students would get most problems correct immediately after having been exposed to the associated learning materials. The assumption proved incorrect for most higher level questions. Moreover, we imagined that the most probable errors could all be identified and addressed in the distractors and their associated remedials. Again, students were much more imaginative in committing errors than the subject matter experts were in anticipating them.

Recognition of these defects was not immediate. The overall impression received from the data was simply that performance in the Problem Books was far short of expectations. Our use of the systems approach at this point was more mechanistic than thoughtful; the plan called for a more "fine grained" treatment of valid items with low performance. Consequently, the number of problems was more than doubled, each remedial was expanded to include considerable detail, and a full scale solution was provided for every correct answer solution.

The burden that this expanded version placed on students' study time has already been mentioned in the Introduction. Achievement continued to be disappointing and a hard look at our data and premises led to revisions in the remedial functions and format of the Problem Book.

Specific remedial frames were no more effective than one general remedial frame which told all students how to approach the problem in the correct way. We therefore eliminated remediation for specific incorrect choices and used an expanded discussion of the correct answer as both reinforcement and remediation for right and wrong answers, respectively.

This alteration eliminated a great deal of page turning, which the students and faculty all found objectionable, conserved student time in extraneous remediation, and eliminated the need for course writers to "second guess" the possible student errors. It also permitted the use of other than multiple-choice questions because incorrect alternatives were no longer a necessary part of the system.

In the last revision it was recognized that objectives are best represented by problems. We termed the problems associated with TO's *core* problems and each core problem had associated with it *enabling* problems corresponding to the enabling objectives.

To relieve some of the demands upon students, we constructed a new format. A core problem is presented first, before any enabling problems, and is followed by a detailed solution.* This provides the student with an exact statement of the behavior which is required, and is an advance organizer. If a student succeeds in solving the core problem, he may proceed directly to the next core problem.

Enabling problems and their solutions* follow for those who were unable to treat the core problem. Finally, at the end of the enabling sequence, a variation of the core problem is presented, the *core prime* problem. The format for each objective, then, is:

Core Problem (and Solution)
Enabling Problem 1 (and Solution)
Further Enabling Problems (and Solutions)
Core Prime Problem

---

*These are not located next in sequence in the Problem and Solution Book, however, but are on some scrambled page to prevent inadvertent disclosure.

This forward branching economizes the student's time and avoids his laboring over required sequences which he has already mastered.

The last major change from the original to the present Problem and Solution Book is the removal of all the management and reference functions. These functions are now relegated to a separate sheet, the Study Guide (see section on Study Guide), because it was wasteful to reprint the large P&S Books for the purpose of making simple omissions, sequence changes, changes in references, or any similar alterations. Thus, the P&S Books are now simply repositories of the more enduring Information Panels, problems, and solutions.

How to Develop the P&S Books

We assume that the core problem statements are available at this stage. The major steps in P&S Book construction, then, are (i) development of core problem solutions, (ii) writing enabling problems and solutions, (iii) development of core prime problems, and (iv) assembly and scrambling of material for the book's construction.

(i) Developing Solutions -- In developing a solution for a given core problem, one should bear in mind that he is developing teaching material. As such, the solutions should emulate good tutorial practice of "walking the student through" the method of arriving at the answer, discussing each step in the process. This permits the student to attend to the specific information that he needs in the context of a problem solution.

A recurring question is "how detailed and comprehensive should the solution be?" Again, tutorial practice is a good guide. Those particulars which have only recently been addressed in great detail may be treated rather briefly in subsequent solutions. The main emphasis should be directed to the newest elements of the objective. When a doubt exists, it is better to include more detail than may be necessary rather than less.

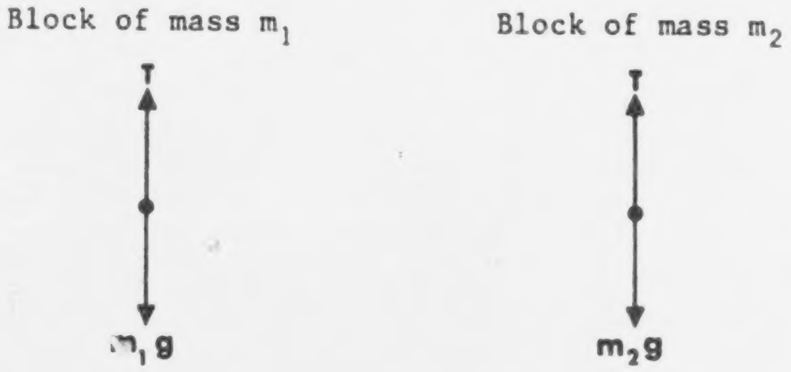
A good problem writer requires a knowledge of prior problems and solutions on the same topic. Clearly, a particular course writer (or pair of writers) should develop all solutions under a particular topic heading (usually corresponding to a chapter in a text).

The accompanying sample problem solution exemplifies some desirable features. The correct answer is provided first, the solution uses diagrams whenever they are likely to be helpful, and symbols are defined and used in lieu of specific numbers. The sample solution is brief in its treatment of the equations of motion, and does not show any steps in the simultaneous equations' solution. When the student sees this solution, he has received intensive exercise in one-body equations of motion, and the ability to solve pairs of linear equations is a prerequisite to the course. The new feature in this problem is the application to two bodies; notice that the treatment of each mass is made separate and distinct despite their obvious similarities.

Sample Problem Solution

CORRECT ANSWER: 3.27 m/sec^2

The free-body diagrams for masses m_1 and m_2 are shown below.



Sample Problem Solution (continued)

Since the two blocks are connected by the same string, the tension is the same in both diagrams.

mass m_1	mass m_2
$\Sigma F_x = 0$	$\Sigma F_x = 0$
$\Sigma F_y = T - m_1 g = m_1 a$	$\Sigma F_y = T - m_2 g = -m_2 a$

Note that the magnitude of the acceleration is the same for both masses and since $m_2 > m_1$, m_2 has acceleration in the negative y-direction and m_1 has acceleration in the positive y-direction.

Solving the simultaneous equations for a one obtains:

$$a = \frac{(m_2 - m_1)g}{m_1 + m_2} = 3.27 \text{ m/sec}^2$$

The emphasis in solutions is on the correct answer, and why it *is* the correct answer. This has been shown to be more useful than identification of a wrong answer as wrong with additional discussion of why the choice was not acceptable. In some cases highly probable errors should be discussed, contrasting the incorrect with the correct answer, but the most useful kind of information is clarification of the correct answer. Therefore, prepare the discussions of the correct answers and add discussions of highly probable errors *only* if you have considerable confidence--and data when possible--to indicate the nature of highly probable errors and misinterpretations.

(ii) Enabling Problems -- The most useful aid for developing enabling problems is a well written solution to the corresponding core problem. Each major step is displayed in the core solution and these steps are, by definition, enabling objectives.

The enabling problems should be constructed to include the same physical principles and mathematical manipulation required by the associated core solution step. It is not necessary or desirable, however, to make every enabling problem an undisguised fragment of the core problem. Clearly, one does not want to encourage mere parroting of the core problem solution.

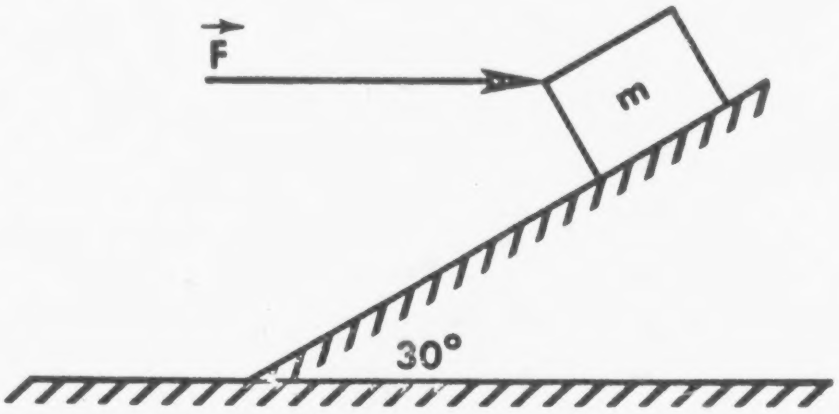
Constructing problems which are parallel but not identical to others did not seem to present any special difficulties to course writers, although the process was as time consuming as creating a problem without any model. The key elements in writing such parallel or equivalent problems are to include all the recently introduced scientific principles, methods, or facts which are contained in the model, and to make sure the complexity level (see "Classifying Learning Objectives" in this report, and TR 5.8) is the same as that of the model.

Most writers found it easy to maintain complexity level even when they did not learn the precise category definitions. They simply made sure that the solution of the equivalent problem required the same symbolic equations as the original problem. This method automatically insured corresponding complexity levels. It is important to keep the complexity levels of enabling problems at or below the level of the associated core problem.

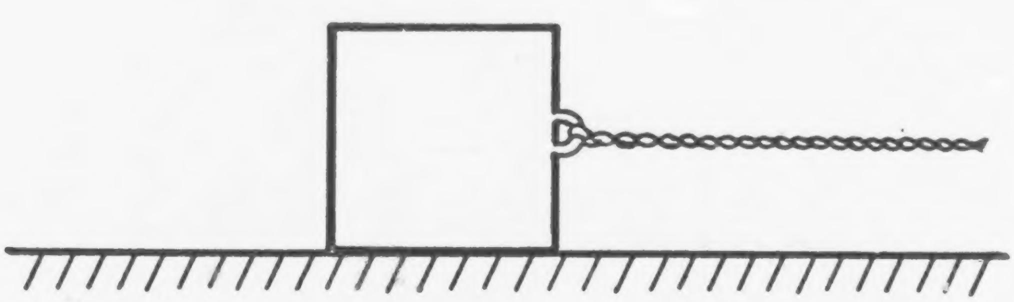
A sample sequence of core and enabling problems is presented here. The solution to the core problem (21) has three key elements: the identification of all forces acting on the block, the resolution of the forces into x- and y- components, and the solution of a set of two linear equations. These are treated respectively by enabling problems 22, 24, and 23. The sequencing does not follow the same order as the steps in the core problem solution because problem 23 is an enabling problem for 24. Thus, the sequencing is quite flexible in an enabling sequence.

Sample Core and Enabling Sequence

21. A force $\vec{F}$, as shown below, of 10 nt pushes a 3-kg block along a plane inclined at 30°. If $\vec{F}$ is parallel to the horizontal surface, calculate the value of the normal force on the block.

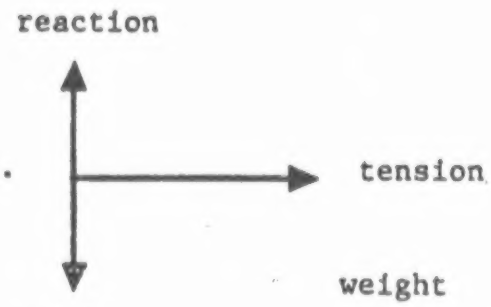


22. A block is pulled along a horizontal, frictionless surface by a horizontal rope as shown below. Which of the following force diagrams applies to the block?

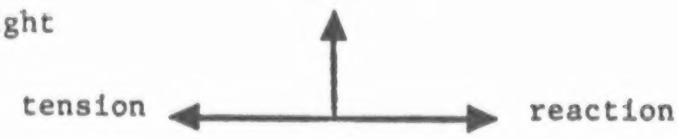


22. continued

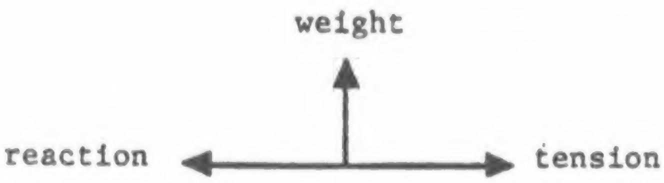
A.


reaction
tension
weight

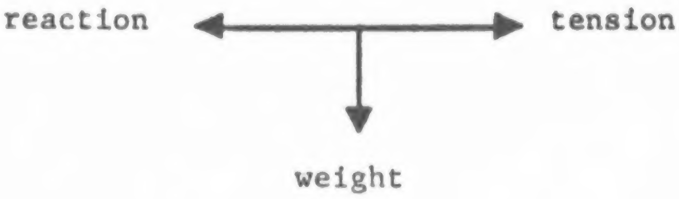
B.


weight
tension
reaction

C.


weight
reaction
tension

D.

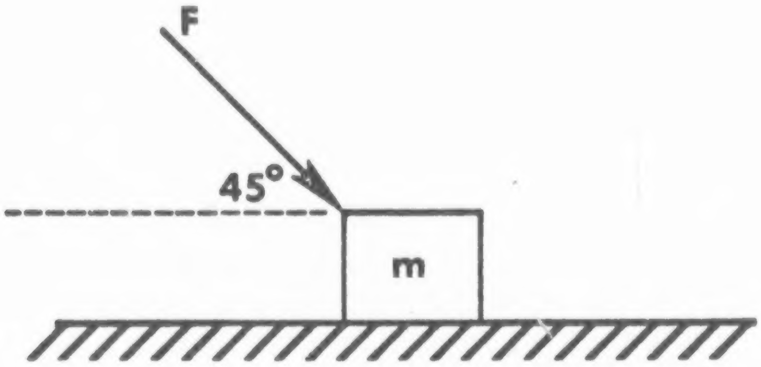

reaction
tension
weight

23. Most physics problems in our course result in the formulation of equations of one or more unknowns. We know that the physics of the problem is complete when there are as many independent equations as there are unknowns. Find y for the following set of equations:

$$10x + 20y = 60$$

$$5x - 45y = -80$$

24. A force of 10 nt pushes a 3-kg block along a horizontal frictionless table. What is the value of the force exerted by the table on the block?



A. 7.1 nt vertically up
B. 36.5 nt vertically up
C. zero
D. 10 nt vertically down

Solutions to the enabling problems must be given the same care as was given to the core problem solutions. Again, new material is to be stressed and it is often helpful to restate new principles, etc., in full in the enabling problem solutions. The procedure is the same as was detailed for core problems in (i) above.

(iii) Develop Core Prime Problems -- For each core problem, an equivalent core prime problem must be constructed. The elements of developing equivalent problems were discussed in (ii). Moreover, the remarks pertaining to core problem development pertain to the core primes as well. Usually, core prime problems will appear rather similar to the original core with variations in the sought-for quantities.

(iv) Construction of Problem and Solution Book -- We found that a convenient unit of subdivision for the P&S book is the *segment* consisting of topical units which correspond roughly to one-half week's conventional work, or a standard textbook chapter. On the average, about five core problems are contained in a segment, although they range from three to seven per segment.

The format of a segment can be regarded in two parts, the problem statement portion, and the scrambled solution portion. Problem statements are listed in sequence with the appropriate information panels as in the following example:

Information Panel
1. Core Problem
2. Enabling Problem
3. Core Prime Problem

Information Panel
4. Core Problem
5. Enabling Problem
6. Enabling Problem
7. Enabling Problem
8. Enabling Problem
9. Core Prime Problem
10. Core Problem

Information Panel
11. Core Problem
12. Enabling Problem
13. Enabling Problem
14. Core Prime Problem
15. Core Problem
16. Enabling Problem
17. Enabling Problem
18. Core Prime Problem

Note that more than half of the core problems are preceded by an information panel and that core problem (10) has no associated enabling sequence. The core problems should be clearly identified; we enclosed each core problem in a rectangular box. A sample page of problem statements is included here (it is only accidental that the core problem appears at the top of the page).

Sample Core Problem -- In a one-dimensional elastic collision between two objects, mass m_2 is initially at rest. If the initial speed of mass m_1 is $u_1 = 1$ km/sec, and $m_1 = 2m_2$, what is the final velocity of m_1?

Sample Core Prime Problem -- A mass m_1 traveling in the positive x-direction collides head-on and perfectly elastically with a stationary mass m_2. After the collision m_1 is moving toward the negative and m_2 toward the positive x-direction, both masses having the same speed. What is the value of the ratio m_2/m_1?

The definition of problem equivalence, however, is broad enough to include problems which are superficially dissimilar. For example:

Sample Core Problem -- A 1/2-ounce bullet traveling horizontally with a muzzle speed of 1500 ft/sec strikes a 5-pound block suspended from a fixed point with 5-foot, massless, inextensible cord. If the bullet remains embedded in the block, how high does the block rise? (Neglect air resistance.)

Sample Core Prime Problem -- A 10-gm bullet traveling horizontally with a speed of 500 m/sec strikes a 3-kg wooden block resting on an icy surface. (Neglect the frictional force between the block and ice surface.) The bullet remains embedded in the block and the combined body strikes a spring with a spring constant k = 30 nt/m. Find the maximum compression of the spring.

After the ordered sequence of problem statements, there follows a scrambled listing of problem solutions. In this case, scrambling means that the solutions are not put in the natural order of presentation, but are listed at random. This avoids inadvertent disclosure by the student while he is reading the preceding solution. Scrambling is easily achieved during the typing process when the draft is being made into hard copy.

As the first step in scrambing, the typist chooses one of the solutions at random and labels this [a]. More than one solution will often fit on a page so the typist then chooses another solution which approximately fills the page (on occasion, three or more solutions can be put on a single page). The second and third solutions on the page are labeled [b] and [c]. See the accompanying sample solution page.

When a solution [a] extends beyond a single page, say page 18, and another solution can be fit below the continued portion of 18 [a], then the first "new" solution on the continued page (p. 19) is labeled 19 [a].

Naturally, a record must be kept of the locations of scrambled solutions. This function is served by an Item Location Sheet (see sample). Here each problem number has a solution location associated with it; eg., 17b means page 17, solution [b]. The other entries on the Item Location Sheet are made later.

We found that paginating by the segment gave a more flexible product for revision purposes. Most of the segments in the physics program have about thirty five printed pages. This is rather a small number to bind individually, so for ease in handling we gathered groups of three to five segments to form *volumes*. The individual segments within one volume are clearly separated by a colored Divider Sheet.

Each volume must be bound so that the pages will lie flat when opened.

SAMPLE SOLUTION PAGE

[a] CORRECT ANSWER: 43 nt

If m_2 is to start moving, the applied force F must be greater than the sum of frictional forces, i.e.,

$$F > f_1 + f_2$$

where

$$f_1 = \mu_{s1} N_1 = \mu_{s1} m_1 g$$

$$f_2 = \mu_{s2} N_2 = \mu_{s2} (m_1 + m_2)\ g$$

Thus the minimum necessary force is

$$F = f_1 + f_2 = \mu_{s1} m_1 g + \mu_{s2} (m_1 + m_2)\ g$$

$$= 43.1 \text{ nt} = 43 \text{ nt}$$

[b] CORRECT ANSWER: 10 nt

First, we treat the blocks as a group to find the acceleration; then we isolate the block of mass m to calculate the force of contact. Since the force of friction is ignored, the sum of the forces in the x-direction is

$$\sum F_x = F = (m_1 + m_2)\ a$$

Therefore

$$a = 2 \text{ m/sec}^2$$

Now for the block of mass m_2 to accelerate at 2 m/sec^2, an unbalanced force must act on it. Therefore,

$$\sum F_x = F = m_2 a$$

$$= 10 \text{ nt}$$

the force acting on mass m_2.

This allows students to work from the P&S book without having to hold their place. We found looseleaf binders to be satisfactory in early versions of the physics program, but we prefer plastic comb bindings with soft covers because they are easier to store and handle.

STUDY GUIDE

The Study Guide is the instrument of internal management for the system. It provides the basic direction for the student's progress through the learning material and leaves his progress record for evaluation purposes. This wet-to-reveal sheet, separate from the presentational material to increase its flexibility, contains reading assignments, homework assignments, and multimedia assignments that are related to the objectives under study in the segment.

The student reads the problem in the Problem and Solution Book, and responds to it on the Study Guide. By using a special pen he reveals the correct answer and the page where the problem solution is detailed. He can then go to that page, to a subordinate enabling problem, or to the next core problem.

The Study Guide structure is exceptionally flexible. It does not require that questions be framed in multiple-choice format alone; problems can be of the completion type, or true/false as well, by leaving room for the student to actively respond to the problem below the wet-to-reveal box and have him compare his constructed response with the correct answer. This method, of course, requires the student to evaluate his own response, but since he is not penalized for being incorrect he will most probably be objectively critical. The emphasis here is on the correct answer and how the problem is solved, rather than the identification of an incorrect answer as wrong.

The Study Guide is flexible also in that it can be modified without any corresponding change to the Problem and Solution Book.

In an attempt to free instructor's time for tutorial assistance, the earliest Study Guide was designed to be machine read. An IBM punch card was inserted into a port-a-punch machine which had an electronic grid under the surface. When the student chose an answer to the multiple-choice problem presented in the branching scrambled text, he recorded that selection by punching through the card with a probe, closing the circuit and making a bulb light under an answer matrix. The lighted square silhouetted the page number to which the student was to turn for confirmation or remedial assistance for his particular answer choice. He then was directed either to return and select another response to the same problem or to go on to the next problem. The punched card was collected at the end of the lesson, supplying information on the student's path of progress to the instructors and course designers.

There were several drawbacks to this method. In order for the page number on the paper matrix to be visible when lighted from behind, it had to be carefully registered, printed densely, and covered from easy viewing. We could not both protect it and reveal it adequately.

The punched cards had to be handled carefully to insure their readability by machine. Students are just not that meticulous. The punches had to be clean jabs, not gouged, or they would spill over into one another.

The need of providing every student with electronic equipment for lengthy course work is obviously costly, and the machinery is less portable and more space consuming than paper matrices with chemically revealed printing.

The course items had to follow the multiple choice format, for there was no means of putting any written material on the tightly constructed punch card or into the paper matrix. Additional directives other than page indicators had to be contained within the scrambled text.

To obviate the electronic equipment and its shortcomings, a chemically imprinted matrix response sheet was devised. Page numbers indicating the associated feedback page were printed with wet-to-reveal ink for each answer choice. By using a special pen a student revealed the page number where he would find feedback for his selection. In addition, the special ink was made to be optically scanned by instructor and computer, since student progress was an important instrument of course evaluation.

The multiple choice distractors in these formats all led to remedial instruction. The incorrect alternatives had been designed intuitively by the subject matter experts, with the intent of "second guessing" the students--often a difficult and inefficient effort. Analysis of the data indicated that many of the incorrect choices went unselected. These time consuming discussions of incorrect answers were no more effective in bringing a student to criterion than a full discussion of correct procedure. A great deal of attention to a wrong answer or procedure may even reinforce this incorrect behavior.

These early Study Guides did not include homework assignments, additional reading, and directive to other media sequences. Because these were all part of the Problem and Solution Book, modification of these materials was impractical. Thus, students' paths through the learning materials could not be easily effected.

Development

Study Guides are developed by segment to correspond to the Problem and Solution Book. This insures flexibility in that whole topics may be omitted or revised without disrupting the Study Guide format of adjacent segments. On the other hand, a segment is likely to be the largest learning unit to be required by a student in one sitting so that only one Study Guide needs to be handled in a study session.

Various items which have already been developed need to be assembled as part of the Study Guide construction. The following must be collected corresponding to each core problem in the segment:

Readings -- Text material for the given objectives has already been selected. A reading assignment is entered on the sample Study Guide as

Reading: HR 10-6

Audiovisuals -- In the physics program, media were developed in *parallel*; that is, illustrated text, talking book, and videotape all treated the same topics in order to provide alternatives for student preferences. Thus, "COLLISIONS" is the title for each of these media and our sample Study Guide simply refers to

Audiovisual, COLLISIONS

without identifying a specific medium. A new project is more likely to have presentations which exist only in one of the media. An obvious modification might be

Talking Book, COLLISIONS

when only a talking book is available.

Information Panels -- These usually summarize the terminal objectives in a form which should be understood by the student before he begins any intensive problem solving. As a consequence, the information panels will ordinarily be referenced just before core problems in the Study Guide.

Core & Enabling Sequence -- Answer spaces in the Study Guide correspond to completion or multiple-choice items in the Problem Book. The correct answer to a completion problem is invisibly imprinted in a box together with the Problem Book location of the detailed solution. A space is provided just below the box for the student to write his answer before he reveals the latent image in the box. The revealed entry for a completion problem is shown below:

1/3 km/sec (11[a])

____________________________(ans)

Multiple-choice items have invisible x's imprinted in each of the incorrect answer selections. In the correct answer position, the location of the solution is imprinted. An example of this multiple-choice entry is:

A	B	C	D
13 [b]	X	X	X

Naturally, if the Problem and Solution Book is not scrambled, only a check is necessary to indicate the correct solution. The student will then simply proceed to the solution in the Problem and Solution Book as a matter of course.

The sample Study Guide shows boxes labeled T and F next to each core level entry. These were included as a policing device to indicate whether a student actually turned to the solution location. This was accomplished by including a very simple true-false question at the end of the solution; if the correct response to the question was not revealed on the Study Guide, it was a strong indication that the item was not read. As we indicate elsewhere, such monitoring is likely to be objectionable to students who are sufficiently mature to use a self-managed system.

Homework Assignments -- Homework assignments will usually appear at the end of a segment because they should not interrupt a basic unit of instruction.

Branching Instructions -- An instruction which directs the student to a place in the Study Guide, determined by performance on an item, is referred to as a branching instruction. An example of such an instruction is found in the sample Study Guide:

> If correct, advance to P 6; if not,
> continue sequence.

In this case, the student is told that if he has successfully completed the core problem, he may go on to the next core problem. Otherwise, he should work through the enabling sequence. This basic branching instruction occurs frequently. Other branching instructions can arise for other conditions:

> If you had difficulty with P 6, read HR 10-7.
> Otherwise, go to Step 9.1.

After all the item references for the Study Guide have been collected, they must be sequenced. We found that a Sub-committee of two course authors could establish an ordering which was generally satisfactory.

The format of the Study Guide is evident from the sample. In the first column, the problem numbers from the Problem and Solution Book appear. Core problems are singled out by putting bars above and below their problem numbers. The second column is simply an identification number for instructions. We labeled according to the core problem that the instruction appears under; the first instruction under core problem 6 is numbered 6.1.

Alternate formats may be devised for Study Guides when a latent image process cannot be used. Perhaps the simplest is to put a code number next to each answer space so that after the question has been answered, the student may turn to a key sheet which provides the "revealed" information next to the code number.

U.S. NAVAL ACADEMY **STUDY GUIDE** **SELF-PACED PHYSICS**

P	STEP	NAME	A	B	C	D	T	F
	0.1	Reading: HR 10-6						
	0.2	Audiovisual, COLLISIONS						
	0.3	Information Panel, "Collisions in One Dimension"						
$\overline{1}$		1/3 km/sec (11[a]) ________ (ans)					✓	X
	1.1	If correct, advance to P 6; if not, continue sequence.						
2			13 [b]	X	X	X		
3			X	19 [a]	X	X		
4			X	10 [b]	X	X		
5		3 (10[a]) ________ (ans)					X	✓
$\overline{6}$			X	X	15 [a]	X	✓	X
	6.1	If your first choice was correct, advance to 9.1; if not, continue sequence.						
7			X	X	X	18 [a]		
8			X	X	X	14 [a]		
9		53 cm (23[b]) ________ (ans)					✓	X

P	STEP	SECTION SEGMENT 12	A	B	C	D	T	F
	9.1	Information Panel, "Collisions in Two Dimensions"						
$\overline{10}$		1 (24[a]) ________ (ans)					X	✓
	10.1	If correct, advance to P 14; if not, continue sequence.						
11		5.0 m/sec (17[a]) ________ (ans)						
12		$v_1 = u_1 \cos\theta_1$ (23[a]) ________ (ans)						
13		2.5 m/sec (21[a]) ________ (ans)					X	✓
$\overline{14}$		1.33×10^5 j (16[a]) ________ (ans)					✓	X
	14.1	If correct, advance to 17.1; if not, continue sequence.						
15			X	X	13 [a]	X		
16			X	X	12 [a]	X		
17		1.4×10^5 j (20[a]) ________ (ans)					X	✓
	17.1	Homework: HR 10-22						

REMEDIATION

At the outset of course development, remediation was considered to be a major component of individualized instruction. The importance of removing deficiencies before students moved on to new material is apparent in the various kinds of remediation provided in the physics course. The entire notion of remedial instruction, and its function, design, and placement, as well as its relation to other course components, underwent considerable revision as course development proceeded.

"Remedial" assumes student failure has identified the need for the remedial work; if remedial materials effectively provide the necessary instruction, then why shouldn't those materials be moved to the front end of the course to prevent the failure from occurring at all? As a result, remedial materials have been redeployed and are presented as learning materials in advance of testing and failure.

The most widely used remedial material is that which provides immediate feedback to the student as he progresses through the learning materials. In our earliest efforts the student's response to a multiple-choice item, the specific distractor he chose, directed him to a page of remediation for that choice. His response was then reinforced if correct; if incorrect he was either told why his answer was wrong or given a hint to shape his thinking, and then sent back to try the problem again.

In that original format, an effort was made to include remedial instruction of this kind for each incorrect answer selection. The data indicated, however, that these time-consuming specific remedial frames were not more effective than one general remedial frame for all distractors, probably because of the difficulty in anticipating student errors.

As a result, we eliminated the extensive remediation at the incorrect answer choice, and expanded the discussion for the correct response. Thus, we were able to reinforce the correct answer or procedure rather than emphasize an incorrect one. The extensive reinforcement is now available to all students, not only the percentage of those responding incorrectly. This eliminated a great deal of page turning, which the students and faculty all found objectionable, conserved student time in extraneous remediation, and eliminated the need for course writers to second guess students. It also permitted the use of other than multiple-choice questions, since all variations of a completion problem cannot possibly be anticipated.

Group remediation was also available to our students. One class hour a week was set aside for students to raise discussions and seek extra assistance. It was originally intended that students would be assigned to lecture sessions covering those topics in which groups of students were most deficient. The time pressures on the professor who could prepare a lecture only after student's weekly worksheets were sorted made this a task difficult to implement.

Instructors listed and maintained office hours for those students requiring and seeking tutorial assistance. Test and study guide results were analyzed by the computer and students having deficiencies were to meet with instructors to resolve problems before proceeding to new work. Details of this session were maintained by the instructor for the student's progress file and for revision purposes. A sample of the Individual Remedial Session form is attached. Professors did not prove to be very reliable in bookkeeping, although they certainly served their tutorial function. As such, these records should not be heavily relied upon for revision purposes.

SAMPLE

INDIVIDUALIZED REMEDIAL SESSION

Date ______________ Student Name ____________________

Time ______________ TO Number ____________________

Suggested Steps For Documentation

Success	*Failure*

(1) Retest of TO Question

(2) Ask student to state briefly what he feels he doesn't understand about the TO Question *(summarize briefly below)*.

(3) Check list of enabling objectives which might be covered to allow student to better understand TO Question.

List of Course Objectives Treated	*Comments*

(4) Record briefly all additional personal inputs that may have been required to enable the student to achieve the TO Question.

Success	*Failure*

(5) Retest of TO Question

In the study of physics, each topic builds upon certain ubiquitous topics and techniques. A failure on the part of a student to master any of these basics is likely to jeopardize his performance in succeeding topics. To rectify deficiencies of this sort, we prepared short (one or two page) "packages", to be inserted in the study guide whereever and whenever their appearance might be called for.

The emphasis in each of these interchangeable packages is on application; most of the titles begin "How To...". Each package contained an example followed by a question. The pragmatic approach was used because a student would choose these packages when he is primarily concerned with another topic.

Although prepared, our experience with extraneous remediation kept us from including these packages in an experimental run. Parts of the "How to" packages were incorporated into the problem solution. The surviving aspects of these packages were not at a sufficiently elemental level to serve the original purpose of providing a reminder to the student of certain prerequisite topics, especially in mathematics. We recommend, however, that course developers consider reintroducing such a remediation component.

Early in our course development we presented audiovisual material at the beginning of each frame together with the reading assignment and supplementary notes. Later, when we expanded our distractor frames, many of the AVs were presented as remedial material in these remedial branches. As a consequence, only students who selected an incorrect answer viewed these remedial AVs.

With our emphasis away from anticipatory remediation, many of the audiovisuals relating to distractors were eliminated. Those AVs which

SAMPLE "HOW TO" SHEET

How to Solve Linear Algebraic Equations

Solutions for N unknowns may be obtained from N independent equations. Using a substitution method, one can solve the first equation for any unknown and substitute the expression obtained in the second equation. The substitution process is then repeated using the second and third equations, and so on. Ultimately, only one equation with one unknown will remain.

Example:

Consider the following linear algebraic equations with unknowns r,s,t:

(1) $7r - 5t = -1$
(2) $3r + 5 = 7$
(3) $r - 25 + t = 3$

Note that there are 3 equations with 3 unknowns.

By the prescription, we 'solve' equation (1) for any unknown, say r:

$$r = (5t - 1) /7,$$

and substitute this expression for r into equations (2) and (3). Now solve the altered version of equation (2) for any remaining unknown, say s:

$$s = 7 - 3 (5 t - 1) /7,$$

and substitute this expression for s into (the updated version of) equation (3). Finally, only one unknown remains: t. We obtain $t = 3$. This result may be substituted back into any two of the original equations, and the whole process may be repeated to find the remaining unknowns.

Find x for the following set of equations (a,b,c,d,e are considered 'known'):

$$a x + b y = 0$$
$$c x + d y = e$$

a) ad / (bc - ed)
b) ad / bc
c) eb / cd
d) eb / (cb - ad)

Please return to Question   on page   .

did not specifically address errors were moved forward as an additional source of information.

An additional remedial technique was found in the original review or "interstitial" segments. These aids were additional distractors called Help 1 and Help 2. Help 1 provided the student with a hint on solving the problem. A simple note like "Three forces are in effect here: weight, tension, and electrostatic repulsion" would provide assistance in starting the calculation. If after reading Help 1 he was still unable to complete the problem, Help 2 would provide additional instructions, a more complete "walk through" of the problem solving procedure. These Helps were well received by the students and faculty, and ultimately evolved into our full solution statement.

A catch-all formal remedial sheet is used for remediation after testing. These have the form shown in the sample remedial sheet. It restates the core problem associated with a problem missed by the student on the test. It serves as a reminder of the broad objective and orients him so as to put his deficiency into proper context. The student may then return to the course materials that relate to that problem.

To further supplement the course materials, self study learning packages, relevant to course topics, were assembled. References to these were provided in the formal remedial sheets.

SAMPLE HELP 1

7-2-4.3 page 96

One simple way to solve this problem is to consider what happens physically. The shells are fired and the boat recoils with some velocity. The velocity of the recoiling boat is very much less than the velocity of the mass of the boat. We need to know the total mass of the fired shells in order to calculate the total momentum of the shells fired. Since the velocity of the boat is small the muzzle velocity may be taken as the velocity in the inertial frame initially at rest with respect to the boat. Application at this point of the principle of conservation of momentum gives the result.

Please return to page 59 and select an answer to Question 3-4.

SAMPLE HELP 2

7-2-4.4

page 100

Let's use the principle of conservation of momentum to solve this one.

The velocity of the boat is small compared with the muzzle velocity and the mass of the fired shells is very much smaller than the mass of the boat. The muzzle velocity is the velocity of the shell relative to the moving boat. We would not expect the boat to recoil with any more than several feet per second so that if we assume that the muzzle velocity is the same as the velocity of the shell relative to stationary ground we cannot make a large error. The mass of shells fired in 5 seconds is

$$5 \times 600 \times \frac{1}{60} \times 2 \times \frac{1}{16} \times \frac{1}{32} \times \text{sec} \times \frac{\text{shells}}{\text{min}} \times \frac{\text{min}}{\text{sec}} \times \frac{\text{oz}}{\text{shell}} \times \frac{\text{slug}}{\text{lb}} =$$

$\frac{100}{(16)(32)}$ slugs.

Momentum is $\frac{100}{(16)(32)} \times 3200 = \frac{10^4}{(16)}$ slug ft/sec. This is equal to the momentum of the boat which is $\frac{2000}{32}$ v, from which we obtain v. Notice that we neglected the mass of the fired shells in considering the mass of the boat.

Please return to page 59 and punch the correct answer to Question 3-4.

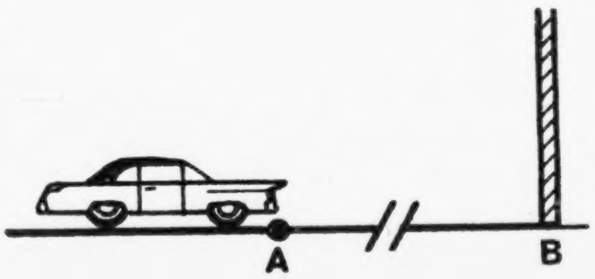
SAMPLE REMEDIAL SHEET

SEGMENT 3

MOTION IN ONE AND TWO DIMENSIONS

Problem 9: Motion in a Horizontal Direction

9.



The distance between point A and wall B is 3000 ft. A car can develop a maximum acceleration of 15 ft/sec^2. The maximum deceleration that the brakes can provide is 30 ft/sec^2. The driver of the car wants to reach the wall B in the shortest possible time, starting from rest at point A. He uses the full accelerating capacity of the car. What is the shortest distance from B at which he must apply the brakes if he is to avoid crashing into the wall?

Reading Assignment:

Halliday and Resnick:	Ch. 3, Sect. 8
Semat and Blumenthal:	Vol. I, Ch. 3, Fr 26-28
Joseph and Leahy:	Part I, Ch. 2, Sect. 8, Fr 9-24, 39-45

Related Problems:

Schaum:	Ch. 4, Nos. 1, 2, 5, 6

AUDIOVISUAL COMPONENTS

The audiovisual components available in the present program include videotapes, talking books, illustrated texts, and lecture/demonstration classes. Videotapes were used in preference to film simply because of convenience and accessibility at both NYIT and the Academy. Talking books contain pictures and diagrams accompanied by a "voice-over" discussion from a portable cassette tape recorder. The illustrated texts have the same picture format as the talking books, but the discussion is provided in print opposite the associated figures. A conventional classroom lecture with demonstrations and blackboard work constitutes the lecture/demonstration.

Experience with the physics program indicates, perhaps surprisingly, that audiovisual materials are not essential components of a self-paced program for highly motivated college students of hard science. Our investigators sought to determine the effectiveness of the various audiovisual components for students with known background variables. No significant differences in performance due to audiovisual materials were detected! However, individual students do have preferences among audiovisual components, and this is the basis of the present system of voluntary selection.

Although the use of audiovisual materials evidenced no significant performances in the operating program (see 5.0, Statistics: 1969 Experiment), we must not conclude that they are without significant value. We believe these materials are useful for teaching "trouble topics" which are often difficult for students to conceptualize. These often require visual or auditory amplification, redundancy and repetition in various perspectives, and motion. Trouble topics had little representation on the Academy's examinations even though some instructors insisted that they were essential to the course content. This disparity between what a student *ought* to know (as revealed in course objectives) and what he is *expected* to know (as revealed in testing) is apparently widespread in the community of science educators. For many professors, it may be that conscience dictates the inclusion of some difficult topics in the course--later, conscience dictates that these topics be excluded from examinations.

Audiovisual materials are also used to provide overviews, enrichment, and to demonstrate the relevance of subject matter in real-world settings and real-life applications. It seems that these are not significant to the task of achieving the specific bahavioral objectives. However, such presentations are likely to stimulate audience *interest* in the subject matter--a very desirable general objective for any course. It is improbable that audiovisuals increased interest or motivation in Academy midshipmen; they have no time for such luxuries. Other less motivated and less goal-directed student groups, however, may profit more from audiovisuals.

Three distinct weaknesses of audiovisual material for a majority of college physics topics are now evident: they are inefficient and time-consuming sources of information (as compared with textbooks, for example); they allow for student interaction only with some difficulty and awkwardness (especially notable for high level objectives); and they are not easy to "skim," so that locating a particular fact or objective may require extensive searching. These weaknesses suggest that audiovisuals should not be recommended casually for run-of-the-mill objectives--even when cost is not an important consideration.

In the initial phase of the program, 48 videotapes were developed to provide broad coverage of major course topics. The objectives to be treated were chosen primarily on the basis of "fundamental importance" to physics. Our investigators reasoned that more precise selection criteria for audiovisuals would evolve from the results of this shotgun approach.

No attempt was made to produce professional looking audiovisuals in this phase--the search for some gross selection parameters did not justify expensive refinements. Videotapes averaged 15 or 20 minutes each, and active responding was provided by presenting a question on each tape. Frequently, questions requiring only a verbal response were asked by a narrator who then paused before giving the answer. Various videotape formats were used including blackboard lectures, laboratory demonstrations with voice-over narration, animation, and demonstrations in real-life situations.

When no performance differences were found to be attributable to audiovisual usage, a new set of videotapes was developed according to a more stringent list of selection criteria. Our psychologists and subject specialists expected that by basing audiovisual development on those factors which were anticipated as most likely to enhance conventional instruction, the influence on performance would be more pronounced. The audiovisual selection criteria for the revised program are as follows:

a. Student difficulty as determined by past experiences in conventional courses

b. Need for motion (videotape only) or serialization of motion (stop motion)

c. Concrete demonstration of abstractions and concepts

d. Imitative guidance whereby students see how an instructor approaches a problem

e. Pictorial media needed for situation not easily verbalized

f. Importance and relevance to the remainder of the course

All course topics were assessed according to whether each criterion was unimportant (blank), important (*), or very important (**), as shown in the sample page *Audiovisual Selection Criteria*. Any topic assigned two or more asterisks was given a videotape presentation--twenty-six in all. The list of criteria has no entry called "need for overview" which we now believe may be one of the most useful roles for audiovisual materials.

The production quality of videotapes was improved in the revision, but high professional veneer was still not justified or sought. A check on the influence of quality was made by developing two versions of the videotape *Kirchhoff's Rules* with one having much more polish. Not only were there no discernable performance differences, but students' preference ratings were also indistinguishable for both versions.

A talking book and illustrated text were developed in parallel with each videotape. The information content is the same for the parallel videotape, talking book, and illustrated text.

Audiovisual Development

After a topic is chosen for audiovisual treatment, a storyboard must be developed. This is a series of sketches with descriptions depicting scenes and pictorial action in a kind of comic strip format. As usual, it helps considerably to begin with a clear statement of the objective. By using rough sketches and a few written remarks directed at attainment

SAMPLE

AUDIOVISUAL SELECTION CRITERIA

	Title	Criterion Guideline					
		a	b	c	d	e	f
1.	Projectile Motion		*	*			*
2.	Newton's 1st Law		*	*			**
3.	Newton's 2nd Law		*	*			**
4.	Newton's 3rd Law		*	*			**
5.	Atwood's Machine	*	*		*		*
6.	Centripetal Force	*	*	*		*	*
7.	Work When Force Varies in Both Magnitude & Direction			*			*
8.	Potential Energy			*		*	*
9.	Kinetic Energy		*	*		*	*
10.	Conservation of Energy			*			**
11.	Conservation of Momentum			*		*	**
11a.	Impulse and Momentum	*	*	*			
12.	Collisions	*	*		*		
13.	Coulomb's Law			*		*	**
14.	Calculations of E	*			*	*	
15.	Flux	**		*	*	*	**
16.	Calculation of E Using Gauss' Law	*			*		*
17.	Capacitors			*	*		*
18.	Motion of a Particle in an Electric Field		*		*	*	*
19.	Kirchhoff's Rules	*			*		*
20.	Definition of B Field	*	*	*		*	*

AUDIOVISUAL SELECTION CRITERIA

	Title	Criterion Guideline					
		a	b	c	d	e	f
21.	The Force Between Parallel Current-Carrying Conductors	*		*	*	*	**
22.	Ampere's Law	*		*		*	**
23.	The Biot-Savart Law	*		*		*	**
24.	Faraday's & Lenz' Law	*	*	*		*	**
25.	Motions of a Charged Particle in Crossed E and B Fields	*	*	*		*	*

of the objective, a storyboard is developed. We exemplify this for *Movement of Center of Mass*.

The stated objective in this case is to exhibit that for every system there exists a point, the center of mass, which moves as though it were a particle with mass equal to the mass of the system subject to a force equal to the total of all external forces on the system. A storyboard directed at this objective is shown on the following page.

Illustrated texts can be prepared from the storyboard by amplifying each frame into a full page figure and by writing the associated descriptive text on a page opposite the figure. In this way page turning is eliminated. The illustrated text for *Movement of the Center of Mass* is reproduced in full.

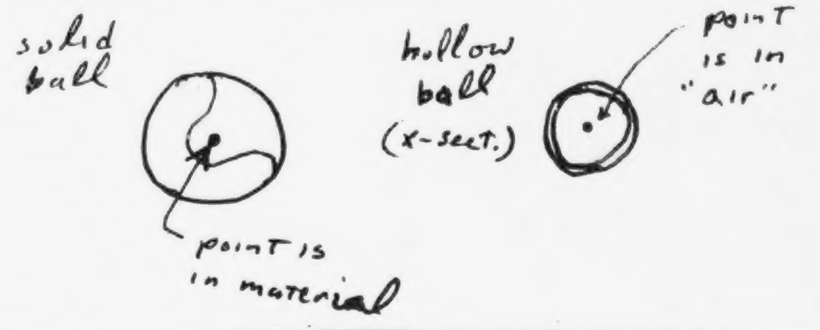
Talking books have the same format as the illustrated texts but with the textual material replaced with a "voice-over" narration supplied by a tape recorder. We found that simply reading the illustrated text onto tape did not provide an acceptable narration. The printed word is more formal than the spoken word, and reading the printed material aloud gave a stilted effect. The text must be slightly reworked to less formal and more colloquial language in order to serve as voice-over narration.

Developing videotape is an art and a good product requires the experience of a professional. We employed the services of a Media Director who worked with the subject matter specialists to develop the finished videotapes. The basic ingredients to be supplied by the subject matter people are the storyboards and guidance in the preparation of narratives.

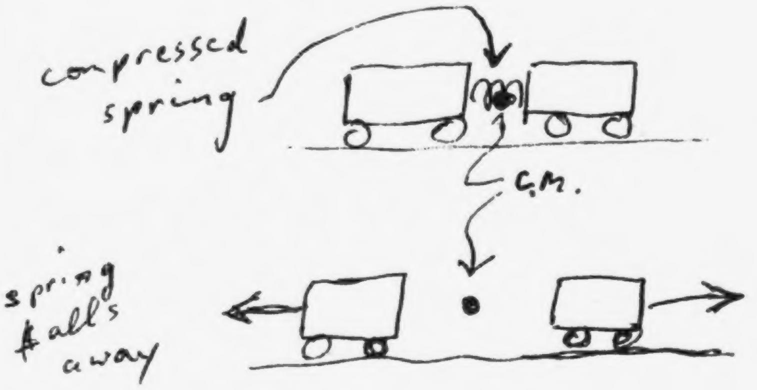
SAMPLE STORYBOARD

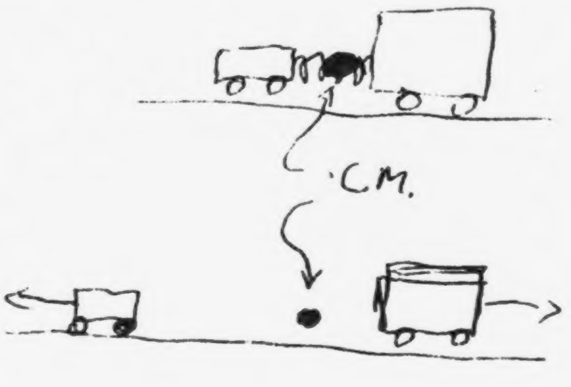
MOVEMENT OF CENTER OF MASS

Define C.M. as point. Illustrate for solid and hollow balls.

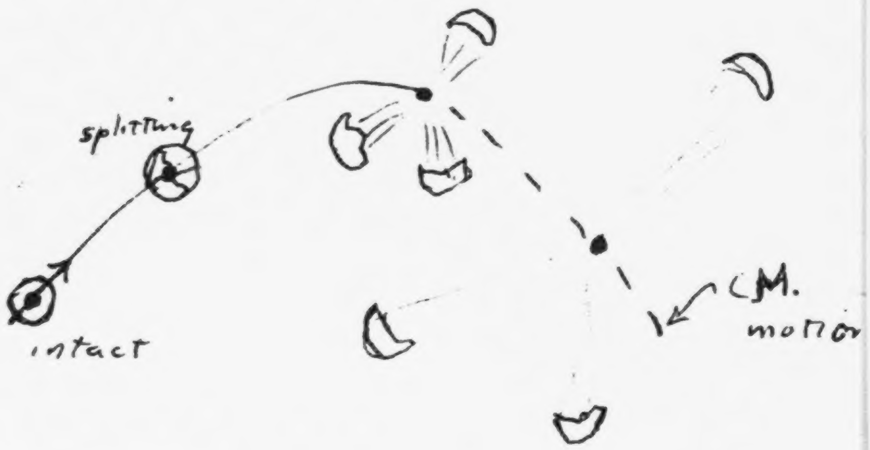

solid ball
point is in material
hollow ball (x-sect.)
point is in "air"

When no external force exists, a stationary C.M. remains stationary (as does a particle which is not subject to a force). Illustrate with cars of equal & unequal masses.


compressed spring
C.M.
spring falls away



When external forces exist, the C.M. moves like a particle subject to the sum of these external forces. Illustrate with bursting shell which would have moved in parabolic trajectory, had it not burst.


splitting
intact
C.M. motion

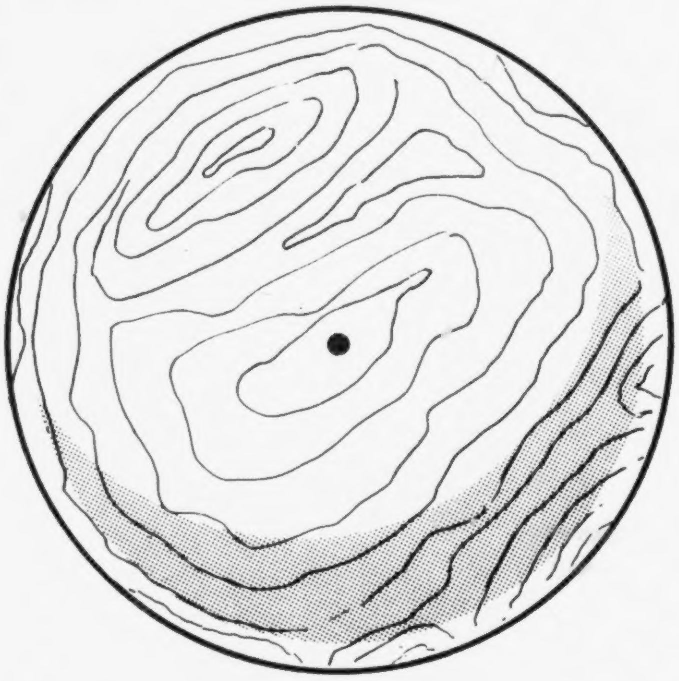
MOVEMENT OF CENTER OF MASS

The center of mass of an object may be described as that single point at which all of its mass appears to act. For an object of uniform density having some regular shape, such as a solid wooden ball, its center of mass is easily located to be at the geometric center, as you can see in Figure 1. Finding the location of the center of mass for a hollow rubber ball is no more difficult--it too is at the geometric center, even though none of the actual mass of the ball is located at that very point.

Many objects, having either regular or irregular shapes, have centers of mass located in space--probably the chair you are sitting on at this moment or the cup or glass you used this morning are good examples to consider. For these objects, the center of mass acts in every way just as it does for one having a center of mass within the medium itself--as with the solid ball.

CENTER OF MASS

(a) for a solid ball



(b) for a hollow ball

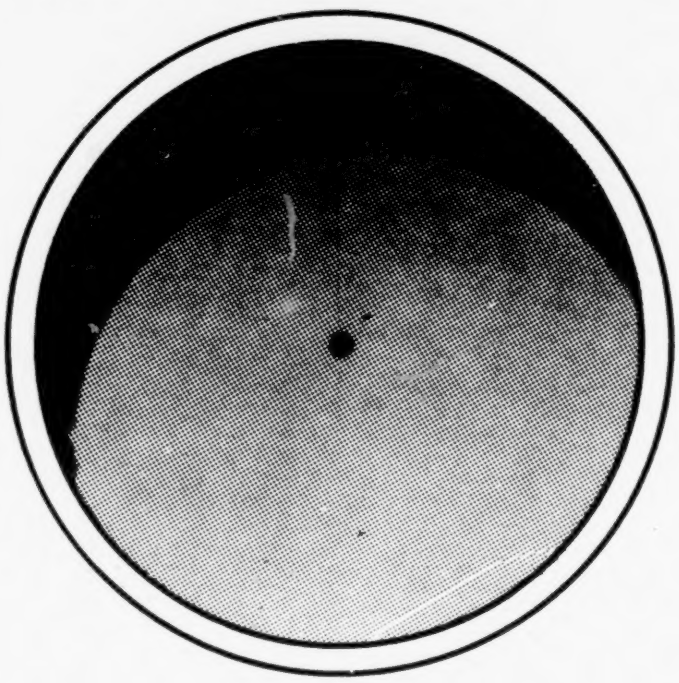


FIGURE ①

The concept of center of mass can be a powerful tool in the study of motion, since all rigid bodies, regardless of shape, volume, or density, can be considered to be point masses acted upon by external forces, thereby simplifying the application of Newton's laws of motion.

A task that at first seems difficult is the analysis of the motion of a body when internal forces are also acting. Let's see what effect, if any, they might have. To do this, let's examine the effect of an explosion on the center of mass of a system consisting of two equal masses. In Figure 2, you see two identical cars about to be exploded apart by a compressed spring. Before the explosion, the center of mass of the system is midway between the cars. When the explosion occurs, each car receives an equal, but opposite force to the other, for the same period of time, giving each similar accelerations. But at any time, the center of mass of the system can be found to be at the same point, unaffected by the explosion.

EQUAL MASS CARS

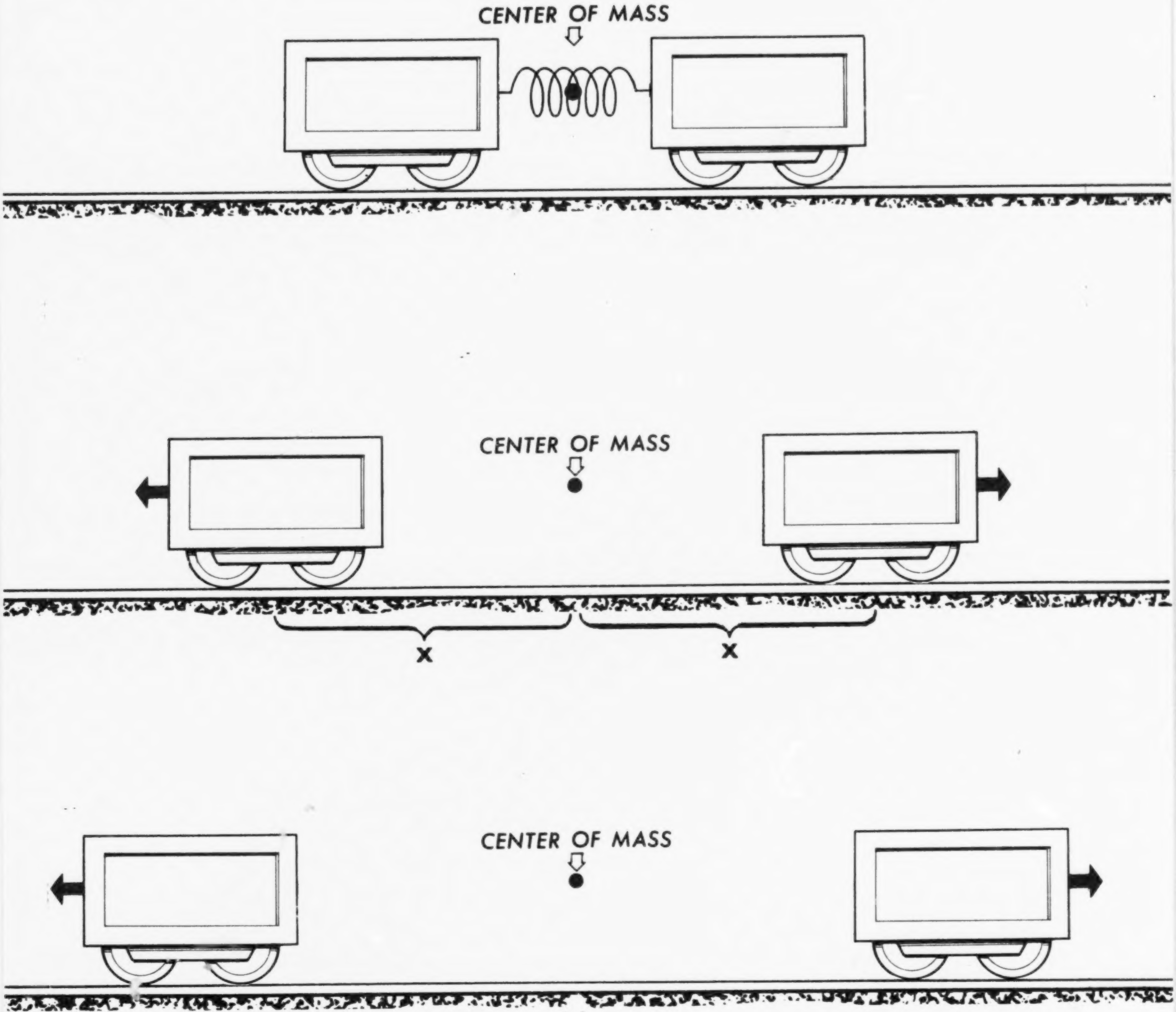

CENTER OF MASS
CENTER OF MASS
x
x
CENTER OF MASS
x'
x'

FIGURE ②

ILLUSTRATED TEXT (3) Fig. 3

You may well ask, what would have happened if two unequal masses were chosen? Let's repeat the explosion, this time with unequal cars; say they have a mass ratio between them of 1:2. Once again the explosion will apply equal and opposite forces on the cars, but this time one car, the lighter one, will accelerate at twice that of the heavy car, thereby moving twice as far in equal time. Consequently, the center of mass of the system remains in the same position, unaffected by internal forces as you can see by examining Figure 3. As a matter of fact, even if the two cars have some initial velocity while linked together, their center of mass would continue to move at that velocity even after the explosion occurs.

UNEQUAL MASS CARS

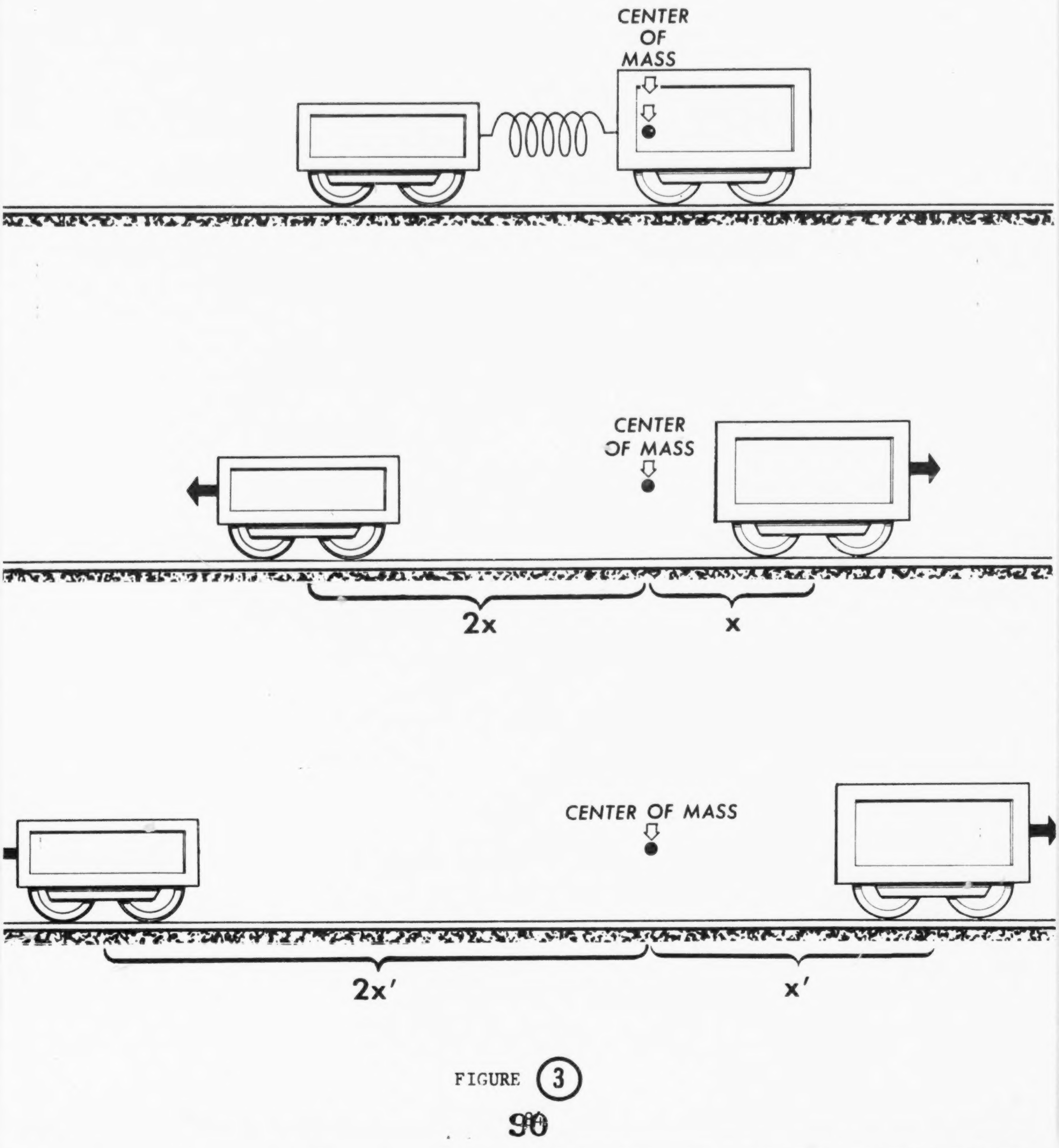

CENTER OF MASS
CENTER OF MASS
2x
x
CENTER OF MASS
2x′
x′

FIGURE ③

Before closing, let's apply these principles to some typical motion problem. A good one to consider would be the motion of an explodable ball as it moves in a parabolic trajectory. Here, in Figure 4, the ball is subjected to some initial accelerating force, and a constant gravitation force, both acting externally, as well as an internal explosive force.

Before the explosion the ball travels intact along a parabolic path governed by the effects of its initial velocity and gravitation. The ball is then exploded into fragments, each moving away from the center of gravity at a rate dependent upon the explosive force and its size, and each still is affected by the initial velocity and gravitation. Since the explosive internal force has been shown to have no effect on the center of gravity, its motion continues along the parabolic trajectory as though the ball had remained intact.

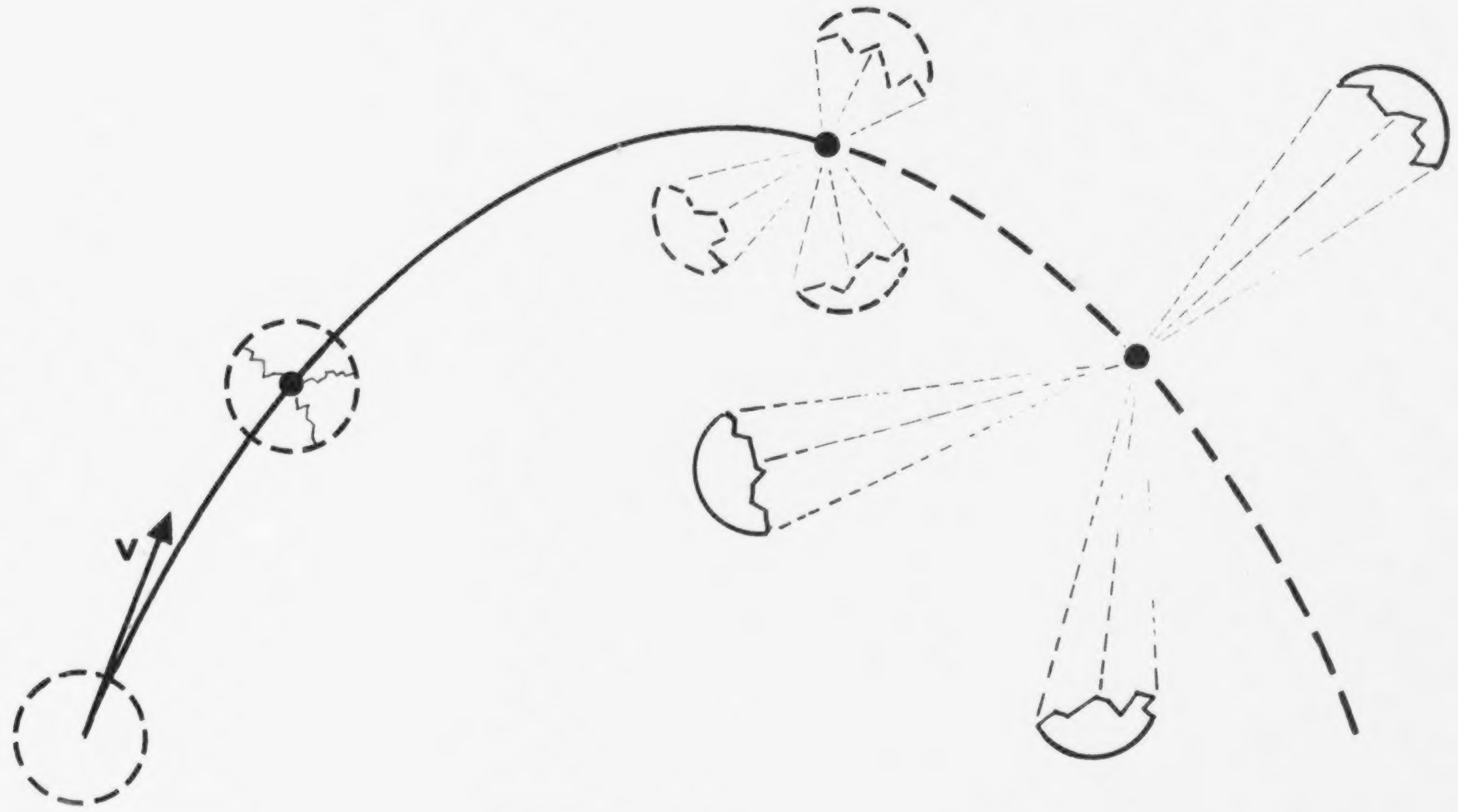


FIGURE ④

HOMEWORK AND READING ASSIGNMENTS

A homework assignment is traditionally a requirement which *must* be satisfied outside the classroom rather than one which *may* be satisfied at home. This distinction blurs in the case of a highly automated course with portable components. Except for videotapes and tests, all components of the program can be carried off campus and administered at home. The institution decides on the mobility of the components; the Naval Academy prefers that only the textbook be available outside the classroom.

Originally, we felt bound to have traditional homework assignments which, for hard sciences, means a reading assignment and some problems from the appropriate textbook chapter. Four textbooks are used in the physics program: Halliday and Resnick, Sears and Zemansky, Baez, and Shortley and Williams. An objection was raised that too much redundant reading was being assigned from the various texts. It was decided that in the first revision of the program one textbook, Halliday and Resnick, should be used as the standard text and the others would be used as supplements. Sections of essential readings were indicated by an asterisk and the supplementary readings were listed in preferential order:

ASSIGNMENT

	Reading	*Homework*
HR	16-7*, 8*, 9*	
SZ	7-4	HR 16-13
AB	4-1, 2, 3, 5, 8, 9; 27-4	

At the same time we made a fixed distinction between reading and homework assignments. Homework refers only to problem assignments.

This assignment form is maintained in the second revision of the program except that readings and homework now appear in the Study Guide rather than the Problem and Solution Book. The present format is shown in the sample Study Guide on the next page. The reading assignment is the first item and the homework assignment is the last item on the sample.

We believe that two more modifications should be incorporated into a new program. First, since the course is now based upon a complete set of all-encompassing core problems, all of which appear in the Problem and Solution Book, the homework problems must be redundant or superfluous. On this basis we recommend omitting homework problems. Secondly, the reading assignments should be annotated with a short phrase or two to indicate to the student what it is he is about to read. Phrases such as "For an overview of electromagnetic theory see...," "For an example of how a radio wave is created see...," and "Philosophical implications of the Second Law of Thermodynamics appear in..." have the virtues of acting as advance organizers and informing the student of those optional readings which are important or interesting to him.

Choosing the reading assignments by working backward from the objectives assures that the primary readings are germane to the objectives. One must be careful, however, to look beyond those readings which directly enable the student to solve the problem at hand. Secondary readings should include overviews and cultural and historical information pertaining to the objective in a broad sense.

1 of 1

U.S. NAVAL ACADEMY **STUDY GUIDE** **SELF-PACED PHYSICS**

P	**STEP**	**NAME**
	0.1	Reading: *HR 16-9/16-12 SZ 7-4
	0.2	Information Panel, "Gravitational Potential Energy"
1		A ☐ B ☐ C ☐ D ☐ T ☐ F ☐
	1.1	If your first choice was correct, advance to 5.1; if not, continue sequence.
2		A ☐ B ☐ C ☐ D ☐
3		A ☐ B ☐ C ☐ D ☐
4		A ☐ B ☐ C ☐ D ☐
5		A ☐ B ☐ C ☐ D ☐ T ☐ F ☐
	5.1	Information Panel, "Gravitational Potential"
6		A ☐ B ☐ C ☐ D ☐ T ☐ F ☐
	6.1	If your first choice was correct, advance to P 10; if not, continue sequence.
7		A ☐ B ☐ C ☐ D ☐
8		☐ ____________________(ans)

P	**STEP**	**SECTION** **SEGMENT 14**
9		☐ T ☐ F ☐ ____________________(ans)
10		☐ T ☐ F ☐ ____________________(ans)
	10.1	If correct, advance to 13.1; if not, continue sequence.
11		A ☐ B ☐ C ☐ D ☐
12		A ☐ B ☐ C ☐ D ☐
13		☐ T ☐ F ☐ ____________________(ans)
	13.1	Information Panel, "Escape Speed"
14		☐ T ☐ F ☐ ____________________(ans)
	14.1	If correct, advance to 16.1; if not, continue sequence.
15		☐ ____________________(ans)
16		☐ T ☐ F ☐ ____________________(ans)
	16.1	Homework: HR 16-24, 16-25

ENRICHMENT

Enrichment materials for the physics program are packaged in one Problem and Solution volume. This enrichment volume characteristically comprises optional problems which are either quite difficult or which cover subtle points. The outstanding fact to be told about the enrichment volume is that no student has ever elected to take it!

The original arrangement of enrichment materials seemed more natural. Individual segments concluded with the enrichment problems and instruction pertinent to that topic. In this way the natural order of progressive difficulty was maintained throughout the segment. Enrichment was distinguished by a statement that the material to follow was optional. However, when the data revealed that students were not doing the optional work, it was decided for pragmatic and psychological reasons to collect the enrichment sections together under separate cover.

Because few students elect to try enrichment exercises, fewer copies of the enrichment volume needed to be printed and stored in this more optional packaging structure. More important, the presence of such additional material seemed to intimidate students who were already having great difficulty in completing the requirements.

In view of the disuse of enrichment material, we examine the purpose of such material. Is it to provide a springboard to further study for very interested students? Is it to establish a superior grade for superior students?

Serious practical considerations discourage the creation of enrichment material for interested students to use as a step toward further study.

The high costs of development and production of these materials, and the very limited audience for them, make enrichment materials highly cost-ineffective items for this purpose. We think that this need can be fulfilled by providing references to articles in such popular journals as *Scientific American* and *Physics Today* (other disciplines usually have corresponding counterparts) and to intermediate textbooks. Of course, in cases where self-paced material has already been developed for higher level courses, these can be taken over directly for enrichment.

The concept of using enrichment material for the purpose of establishing a superior grade deserves the consideration of those implementing the course. The successful completion of all "standard" material might establish a grade of "B" and the completion of additional enrichment material might establish an "A." In using graduated learning material to establish grades, the material should appear as a continuous whole. Only a note in the Study Guide is necessary to flag that "the objectives to follow are required for an "A" grade.

REVIEW

The original review function was served by several interstitial segments which were distributed throughout the Problem and Solution Books. These provided drill and practice on the preceding two or three volumes of material. The format of these segments was similar to the regular segments, with the exception that two additional distractors were available for each review problem: Help 1 and Help 2.

Help 1 provided the student with a hint on solving the problem. A simple note like "Three forces are in effect here: weight, tension, and electrostatic repulsion" would provide assistance in starting the calculation. If after reading Help 1 he was still unable to complete the problem, Help 2 would provide additional instructions, a more complete "walk through" of the problem solving procedure. These Helps were well received by the students and faculty, and ultimately evolved into our full solution statement.

Students complained that review material relating back as far as 1-1/2 months disrupted their concentration and forced them to review material not covered by the next posttest. It was suggested that interstitial segments be rescheduled or eliminated.

The drill and practice function of the interstitials were, in the later versions, collected together to eliminate the disrupting aspect. To provide review for midterm and final examinations, six review segments were prepared, three available before the midterm and three before the final.

This present format is conducive to review whereas earlier versions were not. The Information Panels and problems in the Problem and Solution

Book are not scrambled, allowing the student to look through the material in a straightforward manner, as he would in any text. Previously, students insisted on the addition of an index for each volume in order to locate specific topics.

TESTING

TEST ITEMS

The development of test materials is greatly facilitated by having objectives cast in problem form. A test item is simply constructed as a perturbation of the corresponding core problem. This procedure usually results in a test item at the same complexity level as the core.

In the physics program, it was not possible to test every terminal objective at the core problem level because, for some topics, this would require excessively long test sessions. As a compromise, we tested some objectives at the level below that of the core. These were easily constructed as variations of enabling problems.

Developing Problems

Subject specialists usually have a wide repertoire of problems. Nevertheless, they are frequently called upon to construct "new" problems. It is our experience that this is usually expedited by a procedure of forming an idealized mathematical problem and then putting "flesh" on the skeletal elements. Four basic steps comprise the procedure:

(i) Write the applicable mathematical relations for an idealized case; that is, consider massive particles rather than real objects, abstract fields rather than their causative agents, perfect heat reservoirs and sinks rather than approximate physical counterparts, etc.

(ii) Choose a suitable "unknown" quantity and affect a solution of the equations by inventing some simplifying conditions and "given" information.

(iii) Write an idealized mathematical problem for the situation described above.

(iv) Convert this mathematical problem into a specific physical problem by substituting real objects and situations for the idealized counterparts.

As an example, consider the creation of a core problem on applying the conservation of energy theorem to an object moving in a uniform gravitational field. Any physicist recognizes the idealized situation: A point particle of mass m which has respective initial height and speed y_o and v_o, and a final height and speed of y_f and v_f obeys the principle of conservation of mechanical energy near the surface of the Earth,

$$\frac{m}{2} v_o^2 + mgy_o = \frac{m}{2} v_f^2 + mgy_f, \text{ or}$$

$$\frac{1}{2} v_o^2 + gy_o = \frac{1}{2} v_f^2 + gy_f \qquad (1)$$

In order to make a mathematical problem out of this equation, one must choose a suitable unknown, say $y_f - y_o$. The other items, v_o and v_f, must then be given or implied by the problem statement. Mathematical computation can be reduced at this point by judicious choices for these given items; one such arbitrary choice is to set v_f equal to some fraction of v_o,

$$v_f = \frac{1}{2} v_o \qquad (2)$$

With this simplification, Eq. (1) has the solution

$$y_f - y_o = v_o^2/4g$$

An idealized mathematical problem which incorporates these elements is:

A particle moves near the Earth's surface initially at speed v_o. At a "final" point, the particle moves with speed $v_o/2$. What is the increase in height of the final point over the initial point?

Notice that the mass of the particle is not included since it is not required for the problem solution.

The sterile idealized problem can now be converted to a more physical statement by changing the idealized objects and situations to specifics. By substituting a roller coaster for the idealized particle, we arrived at the following problem:

A roller coaster moves at point A with speed v_o. At point B, the coaster moves with speed $(1/2)\ v_o$. Assuming no frictional losses, what is the height of point B above point A?

A. $3\ v_o^2/8g$

B. $7\ v_o^2/8g$

C. $v_o^2/4g$

D. $5\ v_o^2/8g$

Any number of similar problems may be generated in this way from a formal problem skeleton. In the present example, another substitution for the particle can be a pendulum bob:

A simple pendulum swings through its lowest point at a speed of 8 ft/sec. What is the height above the lowest point when the pendulum bob has a speed of 4 ft/sec?

Of course, the procedure recommended here is not the only way to create good problems. It is simply a categorization of the steps taken most often by our most experienced course writers. Usually, the writers did not trouble to write out an idealized version of the problem, but they agree that it was kept in mind while they transformed to the actual problem.

Elements of Problem Writing

Writing good problems is as elusive and difficult as any technical writing. A few important elements, however, can be watched for by the problem writer and editor.

Most obvious is the fact that problem statement should be correct and the problem should be solvable. Numerical errors which imply that a satellite revolves around the Earth below sea level, or stated conditions which prevent a baseball from reaching the point at which its speed is sought, are very distressing to students and instructors. Most of our authors have committed such errors on occasion. The writer's best insurance against such embarrassment is to have a second person check the problem, or to work in pairs.

Each problem statement must be self-standing in that all symbols are defined (except on occasion constants G, e, h, c, and g) and sufficient context is provided so that the problem would be clear even in isolation. The following example does not meet this requirement:

> Two particles of mass 2 kg and 3 kg, respectively, are moving with a speed of 10 m/sec due east. A third particle of mass 2 kg is moving with a speed of 25 m/sec due north. Find $\vec{P}/M$.
>
> A. 10.1 m/sec at 45° N of E
>
> B. 20.2 m/sec at 37° N of E
>
> C. 10.1 m/sec at 37° N of E
>
> D. 20.2 m/sec at 45° N of E

Even though the symbols $\vec{P}$ and M are used extensively in the study of center of mass motion, this problem is wide open for misinterpretation. One may question the intent behind the statement; do we want the student to make an enduring identification of $\vec{P}$ and M as total momentum and total mass, or do we want him to be able to find the center of mass velocity regardless of the symbolism he chooses? The problem was changed to:

> Two particles of mass 2 kg and 3 kg, respectively, are moving with a speed of 10 m/sec due east. A third particle of mass 2 kg is moving with a speed of 25 m/sec due north. Determine the velocity of the center of mass, $\vec{v}_{cm}$, of the system of three particles.
>
> A. 10.1 m/sec at 45° N of E
> B. 20.2 m/sec at 37° N of E
> C. 10.1 m/sec at 37° N of E
> D. 20.2 m/sec at 45° N of E

Occasionally, one problem will refer to another for information or results. This practice should be kept to a minimum, and only when the problems will always appear as part of the same sequence.

Ambiguity in problem statements is a most insidious trouble to guard against. Ambiguous statements can occur in several ways. Carelessness, unstated assumptions, and words with both popular and technical meanings are the most frequent causes of ambiguity which we have experienced. Some examples will help to illustrate these.

Many questions have more than one correct answer, but the multiple choice format allows only the desired response to appear. Due to carelessness, a second correct answer sometimes appears in the list of distractors. One final examination question read as follows:

> The physical quantities of length, mass and time in the MKS system are:
>
> A. derived quantities.
>
> B. standard quantities.
>
> C. relative quantities.
>
> D. fundamental quantities.
>
> E. none of the above.

In this case, both B and D are correct. Naturally, no short answer or completion problem should have more than one correct answer.

Unstated assumptions often contribute to ambiguity in a problem statement, and they are not easily detected because most subject experts share the same tacit assumptions. In the following problem, no statement is made regarding whether or not the plane has friction, although this makes a considerable difference in the execution of the problem:

> A block of mass M is released from rest on an inclined plane of angle Θ. Find an expression for the acceleration of the block.

Of course other acceptable tacit assumptions are contained in this problem. It is assumed that the system is near the surface of the Earth, for instance. This is, nevertheless, a discrimination which the student is expected to make from the problem context.

Another example from a final examination illustrates an ambiguity which can arise as the result of an inadequate distinction between popular and technical word definitions:

A rocket that weighs 5000 lb. on earth is in free space and fires a small course correction motor, generating a thrust of 60 lb. What acceleration results?

A. 1.2×10^{-2}ft/sec

B. 38.4×10^{-2}ft/sec

C. 1.92×10^{2}ft/sec

D. 2.4×10^{-2}ft/sec

E. None of these

The writer of this problem intended that the word "small" be interpreted as "negligible." Most physicists would interpret it this way. Many students, however, took the word at face value and correctly selected answer E. If such technical meanings are to be ascribed to popular words and phrases, they should be taught as separate objectives.

Unless one is testing arithmetic or slide rule skills, numerical solutions should be made as uncomplicated as possible. Analytical solutions should be required often as both a labor saving measure and as practice in algebraic manipulation, but not to the exclusion of numerical problems.

Finally, we mention a few additional items to watch for. In multiple choice problems, all the alternatives should be non-trivial and avoid any obvious clues (such as syntax). Problems with a remedial or enabling function should not express an attitude of exasperation or condescension. Extraneous information should not be given in a problem unless the specific objective requires a separation of essential and extraneous information.

Problem Format

The self-paced program accomodates problems in multiple choice, completion, and true-false formats. The question of which format is most appropriate for various kinds of questions is addressed in detail in several references. Some rules-of-thumb regarding format which evolved in the physics program are presented here.

Most problems with purely numerical solutions are presented in completion form. Nothing is gained by presenting such problems in multiple choice form, and the possibility of guessing is virtually eliminated in the completion format. An exception exists when a highly probable error can be anticipated. This error can then be incorporated as a distractor for the purpose of analysis and remediation.

On the other hand, multiple choice is the preferred format for problems with symbolic solutions. The reason for this is that there is a great variability in an analytical solution; for example, an answer

$$\Sigma F_x = F \cos \Theta - mg \sin \Theta$$

may also be written

$$\Sigma F_x = F \sin (\frac{\pi}{2} - \Theta) - mg \cos (\frac{\pi}{2} - \Theta)$$

Multiple choice format allows only one correct form to appear.

Problem Review

In addition to the obvious requirement for problem review before students' use, there is a need for examination and revision after a field test.

The test questions must be examined individually in relation to each other and to the objectives they are designed to test. The assumption must be made that there is probably no such thing as a perfect test item, valid in every way, perfectly reliable, testing the related objective at exactly the proper level of complexity, with no ambiguity, and whose structure and content is uncorrelated with intelligence or verbal ability. Having made this assumption, we must then view every test item with suspicion. If a student answers a question correctly, we consider the possibility that the item was too easy, the correct answer was given away, or for some reason the student was able to answer the question correctly without having achieved the objective; if a student answers a question incorrectly, we consider the possibility that the item was too difficult, too ambiguous, the alternatives were inappropriately similar and without an adequate basis for discrimination within the limits of the objective, or that for some reason students who have achieved the objective can still answer the test item incorrectly.

Obviously this approach should not cause the rejection of every test item as either too easy or too difficult, nor should the percentage of students answering the item correctly be taken as a measure of difficulty. Test items are never above suspicion as being major determinants of the answers chosen or given, and independent of achievement or non-achievement of the objective the item was designed to test. For example, if 90% of the students answer a criterion question correctly, it does not mean that the instruction related to that objective is highly effective. It could mean that, but it could also tell us nothing at all about the instruction or about the number of students who achieved the objective--it might mean only that the test item was answerable on some basis other than having achieved the objective.

Some subjective judgments must be made, which may not be strictly data based, in order to evaluate the data, find which test items provide the most relevant and meaningful information and make revision decisions for test items and instructional materials. It is unlikely that a consistent bias in favor of assuming the instruction to be better than it is would be present, since the entire purpose of this review is to increase course effectiveness; any inappropriate judgments of acceptability and adequacy would mean a wasted opportunity to improve the item.

PROGRESS (CRITERION) CHECKS

We recommend that criterion tests covering all terminal objectives be administered at the conclusion of an average week of work (two segments in the physics project).

The usefulness of these tests cannot be minimized. They give feedback to the student on the progress he is making through the course material, and direct his attention to those areas in which he requires additional work. They provide the instructor with feedback of student performance, upon which he should base any tutorial, lecture, or discussion supplementary to the basic course materials. Progress Checks also provide a basis for evaluation, validation, and revision of the instructional system.

Although Progress Checks have been administered at the Naval Academy both as a course requirement and as an optional component, they have not been used for grading purposes. For this purpose, the Academy gave four quarterly Diagnostic Tests and a Final Examination. The Diagnostic Tests sampled all terminal objectives, but due to limitations on testing time, the items were primarily at the lowest levels of complexity (zero and one step). Moreover, the Diagnostics were administered at intervals too widely separated to be useful tools for effecting changes in course sequencing or instructional materials.

We recommend that the Progress Checks replace the quarterly Diagnostic Tests as a method of establishing grades, since they serve as a better indication of student achievement. Progress Checks more closely parallel the terminal objectives since they are alternate forms of the core problems at the same complexity level and they are administered often enough to provide formative feedback that should determine the next instruction presented to the student. Progress Checks promote *criterion referenced* evaluation--a measure of individual achievement of each objective--rather than suggesting comparisons between students (norm referencing).

Both criterion- and norm-referenced tests are intended to discriminate, but they discriminate between different things. A criterion test discriminates between students who have achieved the objective and those who have not. It does not sample the behaviors described by the objectives, but tests them all; it is a *saturated* measure of the degree to which the student matches the descriptions contained in the objectives. The criterion test also provides an evaluation instrument for course effectiveness.

The characteristics of a criterion test are quite different from those of the more traditional test. Traditional norm-referenced tests are designed to discriminate between students according to their relative achievement and, ideally, to produce a "normal distribution" of scores. Norm-referenced tests typically sample behavior and are used when students are to be assigned a grade or where it is necessary to identify differences between students rather than simply determine whether or not they have achieved the objectives.

It is not surprising that many professionals regard criterion-referenced testing as tantamount to cheating. They have tacitly accepted that an examination in basic physics really should test more than was taught; it should help determine scientific *aptitude*, *originality*, and *imagination*. This may serve a useful purpose, but until we know how to teach these qualities it seems reasonable to separate them from examinations purporting to measure gains in knowledge or skill.

Preparation of Progress Checks

The content of each question was determined by reference to the core questions in the Problem and Solution Book, which represent the terminal objectives of the course. Because the core questions were written to test complete mastery of a terminal objective, the Progress Checks proved to be rather difficult questions. In our view, the Progress Check questions are "core double prime" problems.

Questions used were of the multiple choice, true-false, or completion type. (For the details of problem construction, see the section on Test Items.) Five variations of each question were produced, usually by rearranging numerical parameters within the text of the question rather than restating the question in completely different language. Although the Progress Checks were not used for midshipmen's grades, and one Progress Check could have been given all midshipmen, additional copies were required for midshipmen who scored low enough to require retakes.

Time alloted for midshipmen to complete a Progress Check varied with instructor, but was usually 50 minutes. Many midshipmen frequently took longer. Upon completion of the Progress Check, the instructor, having been provided an answer key, graded the Progress Check and either returned it to the midshipman for review or passed it to clerical personnel for statistical analysis and preparation of retake Progress Checks.

We think that the student should receive the graded test immediately, whether or not he successfully completed it. This feedback to the student is a dynamic element of the course.

SAMPLE PAGE

PROGRESS CHECK

T.O. 25 RR

The principle of the conservation of energy may be written as

(A) Energy may be created or destroyed and transformed from one kind to another.

(B) Energy may be transformed from one kind to another, but it cannot be created or destroyed.

(C) Energy may be created and transformed from one kind to another, but it cannot be destroyed.

(D) Energy may be created or destroyed, but not transformed from one kind to another.

T.O. 26 RR

The potential energy for an object of mass m a height h above the surface of the Earth is

(A) $1/2\ mh^2$

(B) $1/2\ mgh$

(C) mgh

(D) $2\ mgh$

T.O. 27 CU

The bob of a simple pendulum (mass m) is displaced from its equilibrium position such that the string (length R) holding the bob is horizontal. When the bob swings to the opposite side, how high above its equilibrium level does it go?

(A) $R/3$

(B) $R/2$

(C) $2R/3$

(D) R

PRETESTS

In order to have a comparison measure of how much learning progress a student is making, Pretests are generally given at the start of a new unit of work. But, more important, a pretest should also serve as an indicator to shunt a successful student onto the next major topic area, without requiring him to spend precious time with unnecessary instruction.

The final version of the physics course incorporated both functions of pretesting by providing a core problem for each topic. It the student is successful on this core problem, he can bypass the subordinate material. An incorrect response on the presented core problem indicates that the student is in need of additional instruction on the objective; his path through the enabling problems can often document his particular difficulty, and obviate it.

Originally pretests in the physics course were administered every four weeks. A test covering so large a portion of course objectives could only sample the instructional material, provide skimpy data on incremental improvement from pretest to posttest, and could not serve simultaneously as a basis for branching students ahead on those topics already achieved.

To remedy these drawbacks, pretests were given weekly during the experimental run of the program. This procedure, however, also had attendant faults. Because time for testing and study was at a premium at the Naval Academy, weekly administration of pretests made an already demanding schedule an unrealistic hardship. Discussion with students and faculty members enlightened the project staff to unspoken sanctioning of students' not expending much effort on attempting pretest problems, while the data merely indicated inability of the students to achieve the problems. Weekly pretests, while not covering as many topics as the previous method, still were inadequate for providing indication for forward branching. Our solution of "pretesting" by core problem at the objective level removed these deficiencies.

DIAGNOSTIC TESTS

Diagnostic tests were prepared for the purposes of providing review for the students and as input to the administration for assigning grades. We feel these aims can be met more satisfactorily through review segments in the Problem and Solution Book and grading based on achievement as indicated by progress checks. We therefore recommend the elimination of diagnostic tests.

We propose that a student who has passed all the progress checks (even when retests were needed) be assigned a *minimum grade* of C (or 75%). In this way the student is tangibly rewarded each week for his progress by accruing a substantial fraction of his final grade. The differential between grades C and B can be established by the mid-term and final, and between B and A by tests on the enrichment material.

At the Naval Academy, where continual testing for the purpose of assigning grades was required, diagnostics were prepared for each quarter of the course. This constant testing, we believe, put an additional strain on the already overburdened physics students. The tests were administered at intervals too widely spaced to be useful tools for effecting changes in course sequencing or instructional materials. The scope of each test was so large that the objectives could only be sampled, and those items included could only be tested at the lowest complexity levels to keep the test length down to the allotted time. We think, therefore, that basing grades on such unrepresentative test items presents an unreliable picture of student achievement.

A sample of diagnostic test questions is attached. Usually five parallel questions for each terminal objective were prepared so that several very similar tests could be constructed for different student sections. This procedure prevents transfer of test information to students who will be taking the test at a later hour.

SAMPLE PAGE

DIAGNOSTIC TEST

T.O. 28 CU

The center of mass of a straight drinking straw

(A) is the axis of the straw.

(B) is the entire outer surface of the straw.

(C) is the point on the axis of the straw equidistant from either end of the straw.

(D) is the ring of points around the center of the straw.

T.O. 29 CU

When a group of particles is in motion, the center of mass moves as though it was a particle with a mass equal to the sum of all the masses of the particles in the group. What is the force exerted on this fictitious particle?

(A) the average of all internal forces in the particles

(B) the sum of all internal forces in the particles

(C) the average of all external forces on the particles

(D) the sum of all external forces on the particles

T.O. 30 CR

Two bodies each of mass 3 kg are moving eastward; one with a velocity of 2 m/sec, the other with a velocity of 4 m/sec. The magnitude of the total momentum of the system is

(A) 6 kg-m/sec

(B) 12 kg-m/sec

(C) 18 kg-m/sec

(D) 60 kg-m/sec

FINAL EXAMINATION

The physics final examinations at the Naval Academy typically comprise 55 or 60 multiple choice questions to be completed in three hours. They are constructed by Academy professors to be norm-referenced tests (see the discussion on norm-referencing and criterion-referencing in the Progress Checks section) intended to assign a spectrum of grades. Both self-paced and "conventional" student sections took the same final examination and, although the self-paced group performed at least as well as the conventional group, the physics course developers felt that this kind of test does not measure the objectives which were taught by the program. (For a full discussion of the Fall 1970 examination, see the report on Course Evaluation.)

Time limitations on a final examination allow only a sampling of the objectives. This time constraint seems also to turn these examinations into speed tests with about three minutes alloted per problem. Contrast this demand for rapid response with the approach fostered throughout the program. Self-pacing encouraged methodical and contemplative work to synthesize all the elements of complex problem solving. Unless the available time for completing final exams is expanded considerably, these tests cannot be regarded as an accurate measure of criteria attainment in the self-paced program.

It is important to recognize that high achievement on rapid answer tests is exactly what many institutions *do* want as their basic course objective. A great deal of pressure is applied in this direction by standardized tests such as the Graduate Record Examinations, professional license examinations, and others. Course developers must realize that rapid answer objectives need to be part of the system if the student is to be properly trained for the race. Thus, appropriate time limits should be set on each problem, and core problems should be sufficiently uncomplicated to be executed in the required time.

Having said this, we want to express our objection as educators to any system which makes test demands so unrelated to the actual use of knowledge. A professional physicist or engineer does not spend his time working rapid fire at little puzzles; he is required to solve many complex problems. The course objectives should prepare students for real activities, not for unrelated test skills.

We think that a final examination should be given. It is a good educational tool in that it prompts students to review and synthesize the course work. Since time will not allow more than a sampling of objectives, the final exam should count only as a fraction of the grade (probably less than 50%). In preparing the exam we suggest the procedures outlined in the sections on Test Items and Progress Checks.

PROCESSES

COSTS

The cost effectiveness of an educational system is often taken as the number of criteria attained per unit cost. While this measure has a certain appeal, it is an abstraction insofar as existing educational institutions do not graduate students on the basis of the total attained criteria. Thus, a more realistic measure of cost effectiveness is simply the number of students processed through the course (regardless of achievement) per unit cost.

Instructor salaries constitute a major cost in education. Academy policy limits class sections to no more than twenty students per instructor. Although many more students can be served by one instructor using the self-paced program, the Academy constraint prevents the realization of a gain in cost effectiveness over the conventional system. Generally, cost effectiveness increases with increased numbers of students. In some cases a gain of 100% or more in cost effectiveness seems likely with the use of the existing program.

Another major cost of education is overhead. Through the use of the self-paced program, there exists the possibility of reducing the required classroom space--a factor which would further enhance the program cost effectiveness.

For educators who are considering developing their own self-paced program, the attractive possibility of a highly cost effective program must be amortized against development and installation costs. These costs vary greatly, depending upon the materials and sophistication desired.

Development Costs

Wages have a wide range of variation depending upon geography, the nature of the institution, and personnel qualifications *not* associated with program development. Man-hours are a more stable measure of costs for course writers and developers. The estimates which follow are based upon minimum man-hours required by experienced personnel for each function. These figures should be increased for an inexperienced team by about thirty to fifty percent to estimate an upper bound on wage costs:

	Days per Semester Course
Selecting course content	10
Writing Course Objectives (core statements) 1-1/2 days/segment × 30 segments/semester	45
Writing Information Panels 3 days/segment × 30 segments/semester	90
Writing core problem solutions 2 days/segment × 30 segments/semester	60
Writing enabling problems and solutions 3 days/segment × 30 segments/semester	90
Writing core prime problems and solutions 1 day/segment × 30 segments/semester	30
Preparation of Study Guide 1/2 day/segment × 30 segments/semester	15
Sequencing material	5
Developing progress checks 1-1/2 days/segment × 30 segments/semester	45
Preparing remedial sheets 1/2 day/segment × 30 segments/semester	15
Classifying learning objectives This function is included in the estimates for writing core and enabling objectives	0

	Days per Semester Course
Storyboard development Approx. 1 storyboard/segment × 1 day/storyboard × 30 segments/semester	30
Writing illustrated text 1-1/2 days/illustrated text × approx. 30 illustrated texts/semester	45
Developing talking book Alter illustrated text into verbal narrative and tape voice over 1/3 day/talking book × 30 talking books/semester	10
Consulting for videotape presentation 1 day/videotape × 30 videotapes/semester	30
Technical editing for all written materials 2 days/segment × 30 segments/semester	60

Those institutions which will undertake the development of their own videotapes or films will need a Media Director. Producing thirty good quality films or tapes of fifteen or twenty minutes' duration will take ten to thirty weeks depending upon the sophistication being sought--fifteen weeks is probably realistic for acceptable quality videotapes. Shooting occupies only a fraction of the time to prepare the audiovisual. Two hour sessions were quite sufficient for the taping of a twenty minute videotape. Camera crew costs (2 to 4 cameramen per session) may be computed on this basis.

The physics program employed both a non-technical editor and a coordinator (see Production). Both these functions can be met by one individual if procedures and formats have been established as presented in this document. The coordinator must be available full time for the duration of the development (not less than twenty weeks for a one-semester course). The coordinator also supervises the typists who must type all the software. An attempt was made to type a finished mechanical at this point. Xerox copies were furnished to proofreaders and subject matter experts, and their corrections and changes were entered on the mechanical by using paste-ups.

Each segment was approximately thirty-five pages of single spaced elite type so that over 1000 pages were typed (35 pages × 30 segments) for each semester. This technical typing is much slower than routine typing of unfamiliar jargon because of the equations requiring Greek symbols, subscripts and superscripts, built-up fractions, etc. A reasonable estimate for 1000 pages is almost three months of technical typing time for production of finished mechanicals for offset printing.

A considerable number of diagrams and drawings had to be prepared for the physics project, and we suspect that other sciences will require a like number. Our full time artist was able to do all the artwork associated with one segment, including that required for audiovisuals, in an average of five days. This production rate was only possible, however, due to uncommon dilligence; we think a more reasonable estimate is about seven days per segment or forty-two artist-weeks per semester of material.

Costs for film or videotape development vary greatly depending upon the production and whether or not the equipment is owned or leased. A prevalent rule-of-thumb for producing film (and videotape as well) is $2000. per minute of film on rented equipment. Acceptable quality film or tape can probably be made for $500. per minute or less, but budgets should not be planned for less without expert advice.

Many institutions have their own printing facilities and can realize a savings by reproducing software in-house. Local rates for commercial printers in the Long Island area varied from $4.50 to $5.00 per page. Quantities had little effect on the price. Wet-to-reveal sheets for Study Guides cost us approximately 9¢ per sheet in quantities of 1000, and the physics project averaged two of these sheets per segment.

Operating Costs

Academy professors have estimated that in a classroom of self-paced students they can serve at least twice as many students as in a conventional classroom. The on-site professor spends all of his time in answering individual questions. Some students appear to need the attention of an instructor, not because he is the only source of the information being sought, but to satisfy some subjective dependence.

A self-paced course requires considerably more grading and processing than a conventional course. In the physics program, instructors were originally assisted by a clerk and computer grading and analysis. A clerk is an important asset during the first trial run because minor difficulties generated by oversights, errors, and miscalculations are much more easily corrected when instructors have assistance. Our course evaluators are now of the opinion that clerks (beyond the trial run) and computer assistance are desirable but not any more necessary for self-paced classes than for conventional sections. The increased load in grading and evaluation is probably matched by a decrease in preparation.

It is evident that a good many trivial questions arise in the self-paced program. Perhaps more than half of all questions can be readily answered by personnel with considerably fewer qualifications than the regular instructor. Senior students with the appropriate major or graduate assistants can serve well in this capacity, but a regular instructor must be present to treat the more difficult questions. This situation can be realized when large numbers of students (40 or more) sit in one room or auditorium so that the "paraprofessional" personnel can move among them, referring the more time-consuming questions to a professor in the same room. Of course, we could not institute this arrangement at the Academy, so we do not know what proportion of paraprofessionals to instructors is reasonable.

Classroom space and its attendant overhead costs can also be reduced by the use of a self-paced course. Independent study does not need to be conducted in a classroom except for viewing videotapes or films. These can be provided in a separate audiovisual room which services many such programs. The on-site instructor does not need a classroom; he may be made available through office hours scheduled for that purpose. Again, it was not possible to experiment with such arrangements at the Naval Academy so we can only speculate that the program would be successful even without class meetings.

PRODUCTION

Production of materials for student use underwent extensive improvement with each modification of the project. Format changes suggested several of the revised methods, while experience in using the materials suggested others.

All materials from the course writers were edited for clarity, consistency, grammar, and style by a production editor. The edited material was then checked by subject matter experts to ensure that no changes interfered with technical accuracy.

At the same time our technical artist prepared the required artwork. This included diagrams, graphs and symbols for all the written material, and for several of the parallel path media (illustrated text and talking book). The other media were also prepared at this time. Videotapes, using storyboard sketches which parallel other media, were taped both at the Academy and at NYIT, taking advantage of the talent on both campuses.

Manuscript for reproduction was prepared using IBM Selectric typewriters, expanding the usual keyboard to include Greek and most mathematical symbols. Unusually large summation signs, etc., were added to the manuscript by pressure sensitive lettering. The manuscript then underwent several reviews: (a) manuscript was proofed against the original copy; (b) a coordinated review was made, including placement and correctness of artwork, and flow through the problems and solutions as compared with the study guide for the segment, pagination, etc.; (c) a technical review was made for subtle errata which might have been overlooked by the nontechnical editor. The finished mechanicals were then given to the printer for offset reproduction, punching, and binding.

Our experience with early phases revealed that mimeograph was a poor reproduction process. Hand-inserted symbols and all diagrams are difficult to put into the mimeograph stencil. Moreover, the legibility is poor, the contrast is inconsistent, and typing errors are difficult to correct. We found that Xerox photocopy was much more satisfactory for limited quantities. For larger quantities, the offset process was most convenient and inexpensive.

The coordination of production must be centralized with all production progress and requirements carefully tracked since so many diverse activities proceed at the same time. Writers, artists, typists, editors, printers, all work on different stages of material preparation. Thus, records must be kept up to date on all aspects of this effort. A great many record keeping devices were used and replaced in the evolution of the program. The most recent and useful charts include a Chart for Material Location, Segment Process Chart, and a Study Guide Process Chart (see the samples in this section).

SAMPLE
CHART FOR MATERIAL LOCATION

SEGMENT # 8	From	To	To	To	To	To	To	To
Reorganization Sheet & Validated Segment	A 6/17	B 6/17	C 6/17					
Problems and Solutions, and First Item Loc. Sheet	C ✓	D ✓						
Edited Problems and Solutions and T-F Questions	D 7/1 ✓	E	B	X				
Information Panels	D 7/1 ✓	C ✓	B 7/6 ✓	E	B	X		to Bob 8/25
Second Item Location Sheet	D 7/1 ✓	E	B					
Study Guide	E 7/1 ✓	B	F	B	X			to T
Diagrams	E 7/22 ✓	B ✓	I 7/1[illegible] ✓	H	B	X		
Posttest	A ✓	C ✓	B ✓	E ✓	B ✓	X 7/7		
AV Selection	D	G						

SEGMENT # 9	From	To	To	To	To	To	To	To
Reorganization Sheet & Validated Segment	A 6/18	B 6/18	C 6/18					
Problems and Solutions, and First Item Loc. Sheet	C ✓	D						To NA S
Edited Problems and Solutions and T-F Questions	D ✓	E	B	X 8/5				via 8/1
Information Panels	D ✓	C	B	E	B	X		
Second Item Location Sheet	D ✓	E	B					to Bob 8/
Study Guide	E 7/22 ✓	B	F	B	X			
Diagrams	E	B	I	H 8/5	B	X 8/5		
Posttest	A ✓	C ✓	B	E	B ✓	X 7/7		
AV Selection	D	G						

7/8/70

ORGANIZATION SHEET

SAMPLE
SEGMENT PROCESS CHART

SEGMENT NUMBERS

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
RECEIVED (complete segment folder)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TYPED questions & IP's Box corgs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
TYPED & SCRAMBLED solutions & police T-F's	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
TYPED AND COPIED FINAL ILS SHEET	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
TYPED AND COPIED STUDY GUIDE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
SENT OUT P&S BOOK (LEE)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	[illegible] [illegible] correct						
SENT OUT COPIES OF ILS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							
SENT OUT COPIES OF STUDY GUIDE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							

	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	1	2	3
REC D (complete segment folder)																							✓	✓	✓
TYPED questions & IP's																							✓	✓	✓
TYPED & SCRAMBLED solutions & police T-F's																							✓	✓	✓
TYPED AND COPIED FINAL ILS SHEET																							✓	✓	✓
TYPED AND COPIED STUDY GUIDE																							✓	✓	✓
SENT OUT P&S BOOK (LEE)																							✓	✓	✓
SENT OUT COPIES OF ILS																							✓	✓	✓
SENT OUT COPIES OF STUDY GUIDE																							✓	✓	✓

SAMPLE
STUDY GUIDE PROCESS CHART

STUDY GUIDES

Seg No.	In Production	Blanks at Printer	Blanks Printed	Mechanical Matrix made	Delivered to Latent Image Printer	Rcd from Printer; Tested	Delivered to Production Manager (PUNCHED STAPLED)	Delivered to Nav. Academy
1	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X
3	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X	X
5	X	X	X	X	X	X	X	X
6	X	X	X	X	X	X	X	X
7	X	X	X	X	X	X	X	X
8	X	X	X	X	X	X	X	X
9	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X
11	X	X	X	X	X	X	X	X
12	X	X	X	X	X	X	X	X
13	X	X	X	X	X	X	X	X
14	X	X	X	X	X	X	X	X
15	X	X	X	X	X	X	X	X
16	X	X	X	X	X	X	X	X
17	X	X	X	X	X	X	X	X
18	X							
19	X	X	X					
20	X	X	X					
21	X							
22	X							
23	•							
24	•							
25	•							

STUDENT ORIENTATION

Because the self-paced course does not follow traditional classroom operation, there is a need to acquaint the student with course procedures. A description of the course, its structure and materials are detailed in the Student Manual which is prepared for student orientation. Our manual will serve as a model for other self-paced courses.

UNITED STATES NAVAL ACADEMY

STUDENT MANUAL

Self-Paced Physics

STUDENT MANUAL

1. DESCRIPTION OF THE COURSE

The self-paced physics course differs from conventional courses in a number of ways. It is largely student-managed programmed instruction. Most of your learning will be derived from reading carefully selected passages in excellent textbooks, simplified written discussions of the highlights of the various subject areas, and the use of audiovisual aids in the form of videotapes, "talking books", and brief, meaty illustrated pamphlets called Illustrated Texts. An instructor will be available for tutorial assistance as well as diagnosis of your progress.

The format of the course permits you to monitor your performance and achievement by means of instant feedback from the visual response mechanism to be described later.

In addition to self-paced theoretical instruction, you will also spend an adequate amount of time in the physics laboratory and attend a demonstration-lecture periodically.

You will always know in advance when a check quiz or an evaluation test is to be given. As a matter of fact, you will determine for yourself when progress checks will be administered to you. In addition to other periodic tests, a final examination will be used to evaluate your achievement.

2. COURSE STRUCTURE

Assigned reading--From standard textbooks, coded as follows:

HR means Halliday and Resnick, PHYSICS FOR STUDENTS OF SCIENCE AND ENGINEERING, fifth edition, combined form;

SZ means Sears and Zemansky, UNIVERSITY PHYSICS, third edition, complete;

AB means Albert Baez THE NEW COLLEGE PHYSICS - A SPIRAL APPROACH, first printing;

SW means Shortley and Williams, ELEMENTS OF PHYSICS, fourth edition.

The required or prime reading assignment for each segment of the course will be identified by one or more asterisks before the chapter numbers. The remaining reading is to be considered supplementary. A typical reading assignment and its interpretation will be presented as a sample later in this Manual.

For maximum effectiveness, all assigned reading should be completed before you begin work on the programmed instruction. This first reading need not be exhaustive because it is anticipated that you will return to certain sections of it time and time again as you work through the segment.

Information Panels--Aside from your textbook reading, much of your factual and procedural information will come from Information Panels presented in the PROBLEM AND SOLUTION booklet for each segment. These Panels are concise discussions relating to the principles and methods of solution involved in the accompanying problems. If you should find that you do not fully understand the material in the Panel for a given section of your work, you would be expected to return to the textbook assignment for clarification.

Audiovisuals--These are important adjuncts to your reading and problem solving. When you are directed to work with a specified audiovisual, you will usually be given the option of selecting one of three media of presentation.

Videotape: a demonstration accompanied by a discussion that you view on the screen of a small videotape playback;

Talking Book: a set of carefully constructed pictures and diagrams accompanied by an audiotape lecture;

Illustrated Text: a set of pictures similar to those used for the Talking Book accompanied by a formal written discussion matched page by page to the illustrations.

Progress Checks--groups of relevant questions which you must answer after completing a specified number of segments. These checks will be used for diagnosis, progress evaluation, and tutorial assistance should the latter be needed.

Quarterly Diagnostics--special test forms administered periodically to assist your instructor in diagnosing possible weak areas in your learning pattern, and to enable him to prescribe remedial work where required. The Quarterly Diagnostics will also be used to evaluate your achievement.

Final Examination--standard examination which provides information relative to your final grade.

Enrichment Packages--for those students whose progress warrants additional, higher level material; to be a student option.

3. PRINTED LEARNING MATERIALS

PROBLEM AND SOLUTION BOOK. (Hereafter referred to as the P&S.) This is bound study material containing the work for three or more segments in a volume. The entire course consists of 45 segments for the semester. The P&S material in a given volume will contain blue title sheets between segments to help you find the one you want quickly. Each P&S contains:

(a) A problem section in which the questions and numerical problems are presented in strict numerical order, to be worked on in sequence.

(b) A solution section in which the correct methods of answering questions and solving problems are presented in scrambled order. Many of these solutions are terminated by additional "true-false" questions to be answered immediately after you study the individual solutions.

(c) Information Panels strategically interspersed throughout the problem section.

STUDY GUIDE. This is just what its name implies: a written guide that you must follow step-by-step, strictly in the order presented, to work your way through the problems, information panels, audiovisuals, reading, solutions, and other check points. The remainder of this Manual will be devoted to an explanation of the way in which all these aspects of your learning are related.

4. HOW TO USE THE STUDY GUIDE

Please refer to the sample Study Guide which is the last page of this booklet. It is a partial mock-up of a segment that doesn't really exist, and will be used for explanation purposes only. If you are to understand how the system works, if you are to avoid blunders when you start work on your first actual segment, you must walk through the following explanation without missing a step. Take your time; be absolutely certain you understand each maneuver perfectly. If you need help in interpretation, ask for it.

Before you begin work on any segment, ascertain that you have the correct STUDY GUIDE by checking the number near the upper right-hand corner, then complete the heading on each STUDY GUIDE sheet.

Another preliminary step: look at the bottom of the STUDY GUIDE sheet and note the number of pages you should have in your hand. Few STUDY GUIDES contain more than two pages. Be sure you have what you need before you start work.

The letter P above the left column means "Problem Number;" the STEPS are also numbered to indicate the sequence of things you must do other than problem solving.

All right. Let's go through the sample.

Step 0.1 The reading assignment for the segment. The required reading is in Halliday and Resnick, paragraphs 49-3 *through* 49-6 and paragraph 49-9. The slash-bar (/) always means from one paragraph through the other, inclusive. The supplementary reading is in Sears and Zemansky, paragraphs 45-6, 45-7, and 45-11. This reading should be gone through at least once before continuing.

Step 0.2 When you have finished your reading, turn to the first page in the P&S for this segment. Read the Information Panel, be sure you understand if fully, then continue.

$\overline{\underline{1}}$ This is the first problem in the P&S. Note the overscore and underscore lines These indicate that the problem is a core type, required of all students in the course. You will find this problem boxed for the same reason in the P&S. The problem you find in the P&S as number 1 is:

How many gallons of regular gasoline could you have purchased with 5 Martian zilches in Septimus, Ohio in the year 1960 and still have some change left over?

A. 1
B. 2
C. 3
D. 4

Now obviously, to solve this problem you would have to know the price of gasoline per gallon in U.S. currency and also the equivalent buying power of a Martian zilch. Presumably, your reading and the Information Panel contains this information but let us suppose that you didn't do any of the reading and so didn't know the answer. So--you're about to make a wild guess, let's say, answer A. At this point you rub the "reveal" pen provided all over the inside of box A for the first question. As you do so, you will see an X appear, showing that the selection was incorrect. Do it now; reveal the X in box A with your pen. (Best results are obtained by rubbing the pen lightly over the surface, then waiting a few moments for the revealed information to darken.)

Making another stab at it, you choose answer B and use the pen bringing out another X. Trying C, you find that the pen reveals the characters 29[a]. This tells you to turn to page 29, item [a] in the P&S where you will find the full explanation of the method used to solve the problem. For this core question, you will also find a very short true-false question immediately after the correct solution. This question reads as follows:

> A Martian zilch is the equivalent of three U.S. nickels. True or False?

You must now use the reveal pen on either the T-box or the F-box for question 1.

If you make the correct true-false selection, a ✓ will appear in the box. If you choose incorrectly, *an X will appear in the box.* The true-false questions are usually so simple that you will be permitted few, if any, errors in this part of the work. Getting one of these T-F's wrong is a pretty sure indication that you are not reading the solutions. You must avoid this.

Let's go down to the next step.

Step 1.1 You are now being given an option. If your first choice was correct, you will be permitted to skip over the next four questions and advance to the next Information Panel. If you answered incorrectly, even once, you must go through the remedial loop consisting of questions 2 through 5.

We are assuming that you missed question 1, so let's go through this loop together.

2 Problem 2 in the P&S. It is not scored, hence it is not a core problem. It reads as follows:

> It is predicted that a gallon of regular gasoline will sell for $1.05 by the year 1998. If this is roughly 3-1/2 times the price of gasoline in 1960, how much did one gallon cost in 1960?

This is *not* multiple-choice. It's a completion type of question where you must write in the answer. So, write your answer on the line below the rectangle for question 2. The answer is, of course, 30¢ because $1.05 is 3-1/2 times 30¢. After writing it in, reveal the answer in the rectangle with the pen; the answer 30¢ will appear accompanied by the referral page and item 14[c]. Turning to the referral, you find the solution worked out for you to check your own thinking. Problems that are not core types are not accompanied by true-false check questions, so you're ready to go to question 3.

Let's interrupt the sequence for a moment. Even if you were able to answer the original core question correctly the first time, *you should go through the remedial loop anyway if you have any doubt at all about the method of solution or the answer.* You may have guessed at the right answer, or you may have made two errors that canceled out. In any case, if you feel that your choice of the right answer was a fluke in any way, we urge you to go through the remedial loop.

3 Problem 3 in the P&S; it is not a core problem. Here it is:

> Ten Martian zilches will buy exactly the same number of 2-1/2 inch McIntosh apples in a given market on a given day as two U.S. dollars. Thus, one zilch is the equivalent of
>
> A. 10¢
> B. 20¢
> C. 40¢
> D. 60¢

A glance at the STUDY GUIDE corroborates the fact that this is another multiple-choice question. Apparently 10 zilches is the equivalent of $2.00, so one zilch must be worth 20¢. This is answer B, so if you use the reveal pen in box B you will bring out the instruction 18[b] indicating that page 18, item [b] in the P&S has the solution. Whether you were right or wrong in your selections, it is important that you read and understand the solution. If you had chosen any answer other than B, you would have revealed an X as before. There is no true-false question, hence you can now go on to question 4.

Here is your first modified true-false question:

> True or false? Five martian zilches will purchase *more* milk than 20 U.S. dimes.

Note the italicized word. Read the statement and (a) if you decide it is true, simply ink the T-box on the STUDY GUIDE; (b) if you feel that it is false, write a word that can replace *more* and thereby make the statement true. *After* you have written the correction word on the line under the F rectangle, then, and only then, you are to reveal the answer with the pen. In this particular instance, the correct answer is "false" and you would write in the word "less" in place of *more*. Your reveal pen will bring this out, too. If you had selected "true" as your answer, the pen would have revealed an X inside the T-box. So, after writing "less" you would see revealed: "less (21[d])." At this point in an actual lesson, you would turn to this page and item in the P&S and read it carefully before continuing the sequence.

Continuing with the remedial loop:

5 Another multiple-choice question:

> In order to have filled your 18-gallon tank with gasoline in 1960 in Septimus, Ohio, you would have spent at least
>
> A. 15 zilches
> B. 21 zilches
> C. 23 zilches
> D. 27 zilches

The correct answer is, of course, 27 zilches since each zilch is worth 20¢ and each gallon costs 30¢, so you would reveal box D and find inside the instruction "27[b]." After reading the solution, you again encounter a check T-F question which is then answered as before by revealing either the T or F box in question 5. Any answer other than D above would have revealed an X just as described for the previous multiple-choice question.

Step 5.1 Everyone is now expected to devote some time to the Information Panel, "The Currency of Venus" and then

Step 5.2 select the medium he wants for running through the audio-visual, COINAGE AND BILLS OF THE INNER PLANETS.

After that is finished, everyone starts once again on an equal footing with the core question 6.

And so forth.

U.S. NAVAL ACADEMY **STUDY GUIDE** **SELF-PACED PHYSICS**

P	STEP	NAME	P	STEP	SECTION SEGMENT 60
	0.1	Reading: HR*49-3/49-6;*49-9 SZ 45-6, 45-7; 45-11			
	0.2	Information Panel, "The Currency of Mars"			Note: In this sample "walk through", we have not included the Information Panels nor any set-up P & S. The problems that would normally appear in the P & S are given in the Student Manual for explanation purposes.
1		A ☐ B ☐ C ☐ D ☐ T ☐ F ☐			
	1.1	If your first choice was correct, advance to 5.1; if not, continue sequence.			
2		☐ ________________(ans)			AND SO FORTH
3		A ☐ B ☐ C ☐ D ☐			
4		T ☐ F ☐ ________________(ans)			
5		A ☐ B ☐ C ☐ D ☐ T ☐ F ☐			
	5.1	Information Panel, "The Currency of Venus"			
	5.2	Audiovisual, COINAGE AND BILLS OF THE INNER PLANETS			
6		☐ T ☐ F ☐ ________________(ans)			
	6.1	If your answer was correct, advance to 9.1; if not, continue with sequence.			
7		☐ ________________(ans)			

FACULTY ORIENTATION

During the early stages of development, faculty orientation was primarily through informal progress reports at regular weekly meetings of the Academy's Physics Department. These informal reports continued although the general faculty was not involved in actually administering the experimental course during the early phases of the project.

The faculty was encouraged to visit the multimedia room, review the course material and discuss the project. Their impressions and comments were recorded, and their recommendations and questionnaire responses were incorporated into the revision process.

The faculty review was of great assistance to the course developers in the revision effort, but in addition it provided the faculty with "hands on" familiarity with the instructional methods and materials, which in turn increased their appreciation of the project.

Since the degree of cooperation and usefulness of faculty members was very closely correlated with their degree of involvement in the development of the program, course evaluators strongly suggest that the on-site instructors participate in the development effort. Naturally, this is not possible when installing an existing program, but in such cases instructor participation is not as critical, since a revised and validated program is nearly self-standing.

The Instructor Manual is reproduced here as a self-explanatory description of the tasks assigned to the on-site instructors.

INSTRUCTOR MANUAL

UNITED STATES
Self-Paced
PHYSICS
NAVAL ACADEMY

PREFACE

This manual was prepared as a reference and guide for Instructors of the Naval Academy Self-Paced Physics Course. Additional orientation is provided by the Course Manager.

Contained herein are:

1. Notes to the Instructor,
2. A description of the Management Sequence, and
3. A flow-chart which reflects a general overview of

the operational functions of the course.

It is suggested that the Instructor familiarize himself with the course materials and the following student "hand-outs"-

Course Policy

The Student Manual

The Self-Paced Laboratory

NOTES TO THE INSTRUCTOR OF SELF-PACED PHYSICS

1. Introduction

The methods and operation of the self-paced physics course may seem strange to new instructors as well as to the students. This information is presented to assist the instructor in developing his individual class policies. It is presumed you are familiar with the Student Manual and Course Policy Statement.

2. Objective

The objective of the course is to enable each midshipman to complete the tasks defined by the Terminal Objectives (TOs). If you have not done so previously, you should read the TOs, as they constitute the most accurate definition of course content. Because of the way the Problem/Solution books have been constructed, successful completion of all the core questions should cover all the TOs. Since the core questions were also designed to provide a path for fast students, they are frequently complex problems that combine elements of several TOs. Due to the limited time available for testing, the body of TOs is sampled randomly during Progress Checks and Diagnostic Tests.

NOTES TO THE INSTRUCTOR OF SELF-PACED PHYSICS (Cont'd)

3. Class Atmosphere

There are few constraints on how you use class time to move the students through the material. If your class size permits, you are encouraged to use Room 203 as your regular classroom. Initially, a certain amount of encouragement may be needed to steer the midshipmen to the various media. You should try as many of the media as time permits yourself so you can recommend a particular Audiovisual if a midshipman is having trouble in a specific area. You may wish to add additional demonstrations or conduct small topical lectures occasionally. Comprehensive reviews prior to Diagnostic Tests are frequently given.

3. Student Progress

One of the by products of the course organization is the early identification of potential failures, before they reach the Diagnostic Checks. This early identification can be done most effectively by careful screening of study guide responses and progress check responses. The individual prescription for assistance is in your hands, but the early identification of these individuals and the variety of materials available should provide you with considerable flexibility.

5. Areas of Concern

a. Minimum Lecture. You, as well as some of your midshipmen, may feel uncomfortable, initially, because you are not conducting lectures during most of the class time. Experience has shown that most students adapt readily to the self-paced class routine within four to six weeks. You may choose to lecture frequently; however, you will probably have little time left to grade progress checks or counsel slow students, except in EI (Extra-Instruction) Sessions. Another by-product of the course organization is to move a substantial amount of student counseling and remedial work into the classroom.

b. Student Progress. Because of the great amount of material covered by the course, you will soon find students dropping well behind the average (or, from your view, a desirable) class progress. Your success in keeping the class moving will be limited only by your imagination. One reason for the apparently slow class progress may be confusion between a very weak physics student and a good student who chooses to "pace" himself to the speed of slower classmates. Careful screening of study guide and progress check responses can usually separate the two.

The Management Sequence

1. Each student is issued one prime textbook; at least two other supplementary texts are at all times available in physics or in the library.

2. Each student is issued a Student Manual intended to supply the student with all the procedural information required.

3. Course work begins with the issuance of Segment 1 of Problems and Solutions and the Study Guide for the same Segment. The Study Guide is a latent image type on which sequencing information is revealed by means of a special crayon.

4. The Study Guide features are:

(a) A reading assignment indicating prime reading and supplementary reading, both clearly identified.

(b) Core problems identified by score lines over and under the problem number.

(c) Remedial loop problems ("enabling problems"). The instructions for short-circuiting the loops, or following them, are contained in the Study Guide for each individual set.

(d) Titles and directions for Information Panels contained in the Problems and Solutions.

(e) Titles and directions for Audiovisuals. These are available in three formats:

(1) Video tapes;

(2) Talking Books;

(3) Illustrated Texts

(f) Homework assignment, generally in the form of additional problems in the prime text.

5. The Problems and Solutions features are:

(a) Section 1: Problems and diagrams in numerical sequence.

(b) Core problems identified by enclosing each one in a box.

(c) Information Panels preceding core groups.

(d) Scrambled problem solutions: directions for reaching solution is revealed only in the Study Guide when correct answer is chosen.

(e) Each solution for core and core-primed questions is followed by a true-false question whose answer is derivable from the solution to which it pertains. These TF's are answered in special boxed sections of the Study Guide. NOTE: Each core problem which is answered incorrectly requires that the student follow the remedial or enabling loop which always concludes with another problem having the same conceptual basis as the core problem initially missed. Such problems are called "core-primed."

(f) The scrambling process used for the solutions is extremely difficult to compromise. The time required to short-circuit the response pattern is expected to be too great to make it worthwhile.

6. The Progress Check. This is a form of test which follows a unit of work, usually three successive Segments. The Progress Check is graded by the teacher. The performance of the student is evaluated and he is then guided into one of the channels indicated below. To be eligible for the Progress Check, the student must submit to his instructor all of the relevant revealed Study Guides for that unit.

(a) Using a predetermined cut-off grade, the student is given the "go" signal if his performance is above this level. He is also given a set of remedial suggestions in the form of reading, programmed material, films, etc.

(b) If his performance falls below the cut-off, he is given a "stop" signal with remedials, after which he re-takes a Progress Check. Questions on these checks will be randomized so that no two students ever take exactly the same examination, nor does the same student take the same check on the second round.

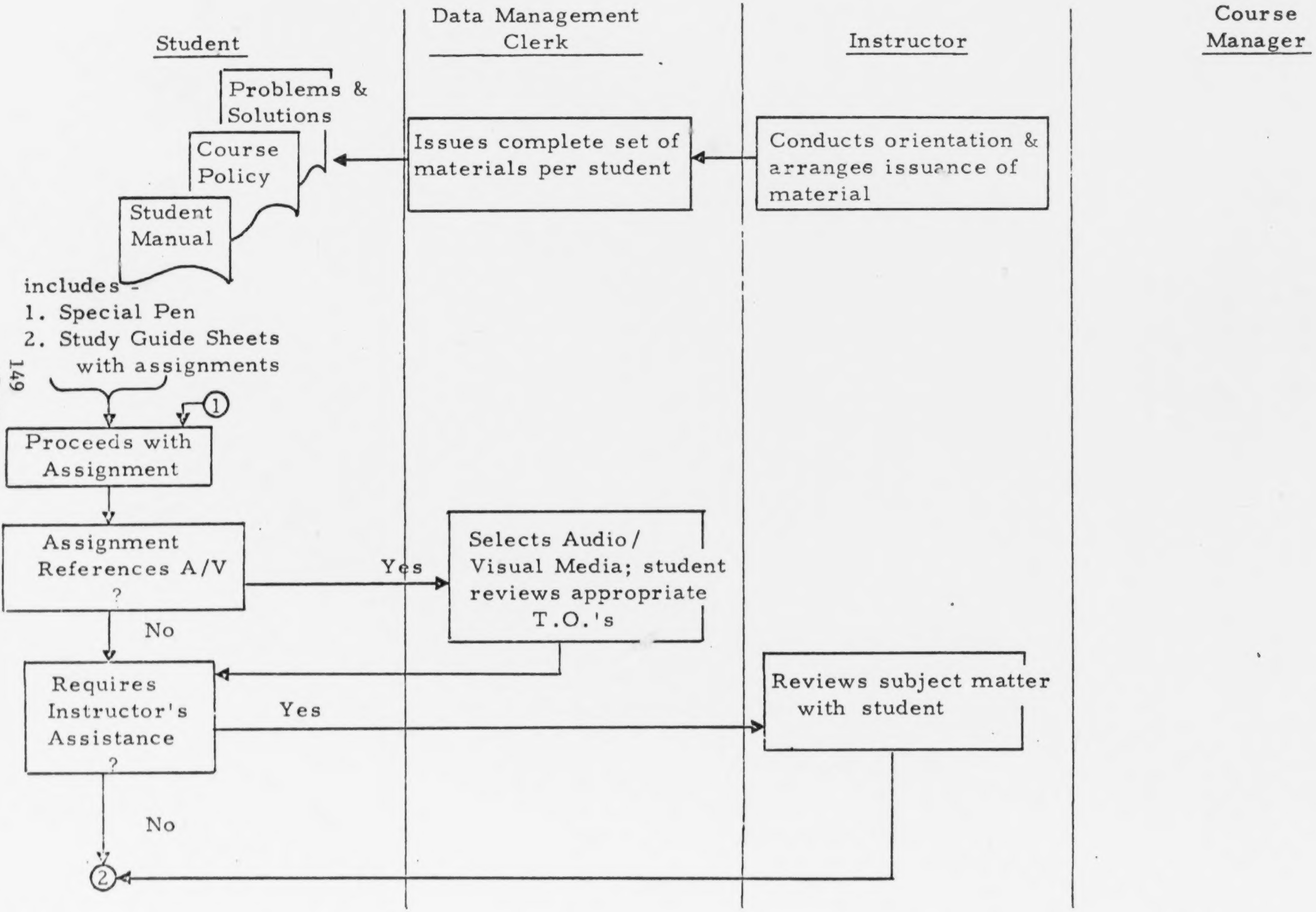
(c) If his performance falls below cut-off on the retake, he will be given individual tutorial assistance and required to take a third test. Disposition of the student after the third failure will be left to the chairman of the physics committee at the Academy.

7. Quarterly Diagnostic Tests. These tests will be carefully generated to test for recognition and recall, understanding of concept, ability to recognize concepts which appear in problems, and ability to solve problems. These tests will all be of the multiple choice variety, with a response mechanism suitable for computer grading. One of the quarterly diagnostics will replace the mid-term examination and the last of them will be administered about one week before the standard final examination.

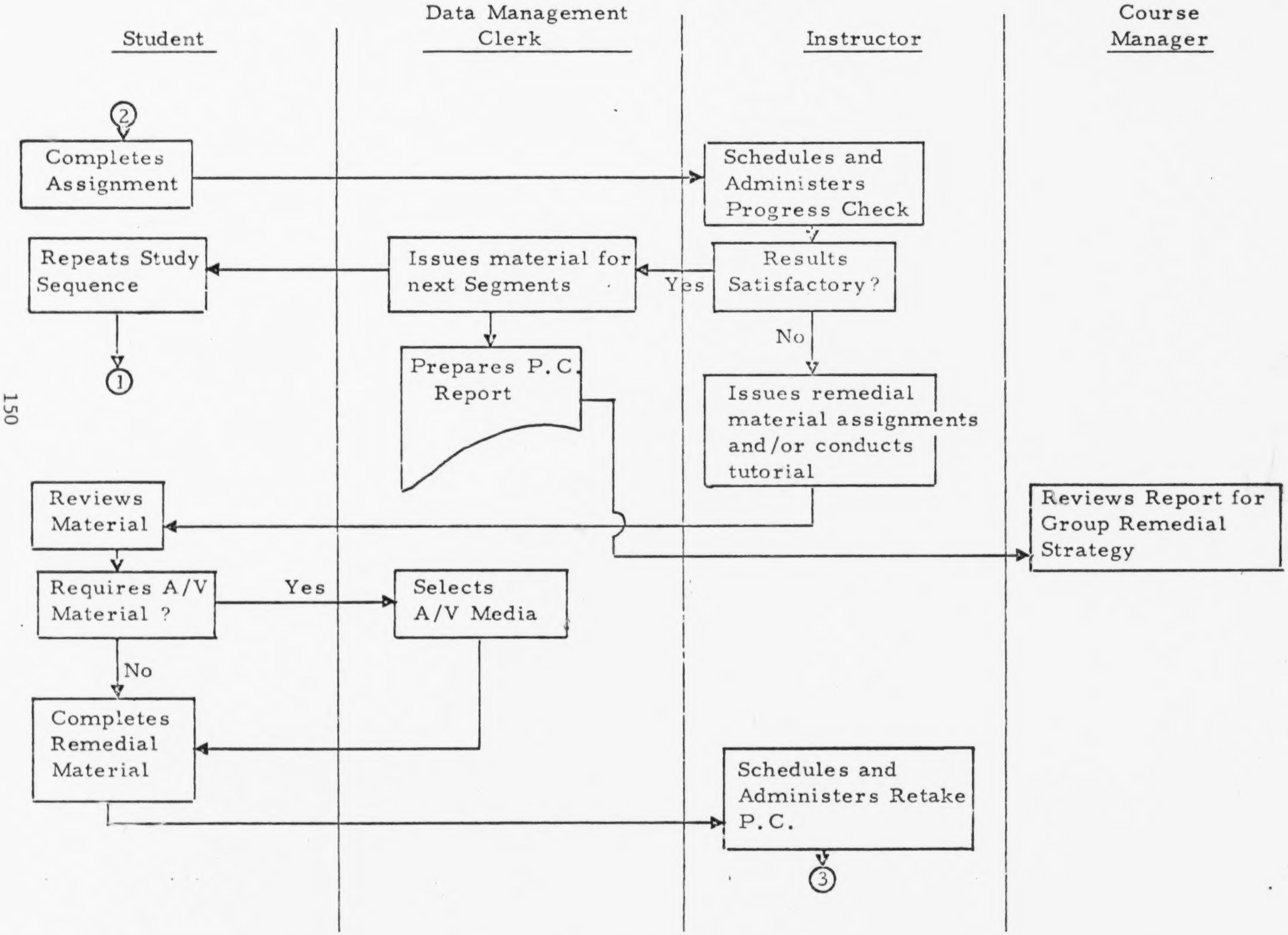
8. At the end of each quarter the instructor will submit a diagnosis and recommendations based upon study guide responses, performance on Progress Checks, and quarter diagnostics. Possible recommendations include continuation of sequence, repetition of specific segments, further use of other program texts, additional tutorials, and dropping out.

Flow Chart

SELF-PACED PHYSICS COURSE (Page 1 of three pages)

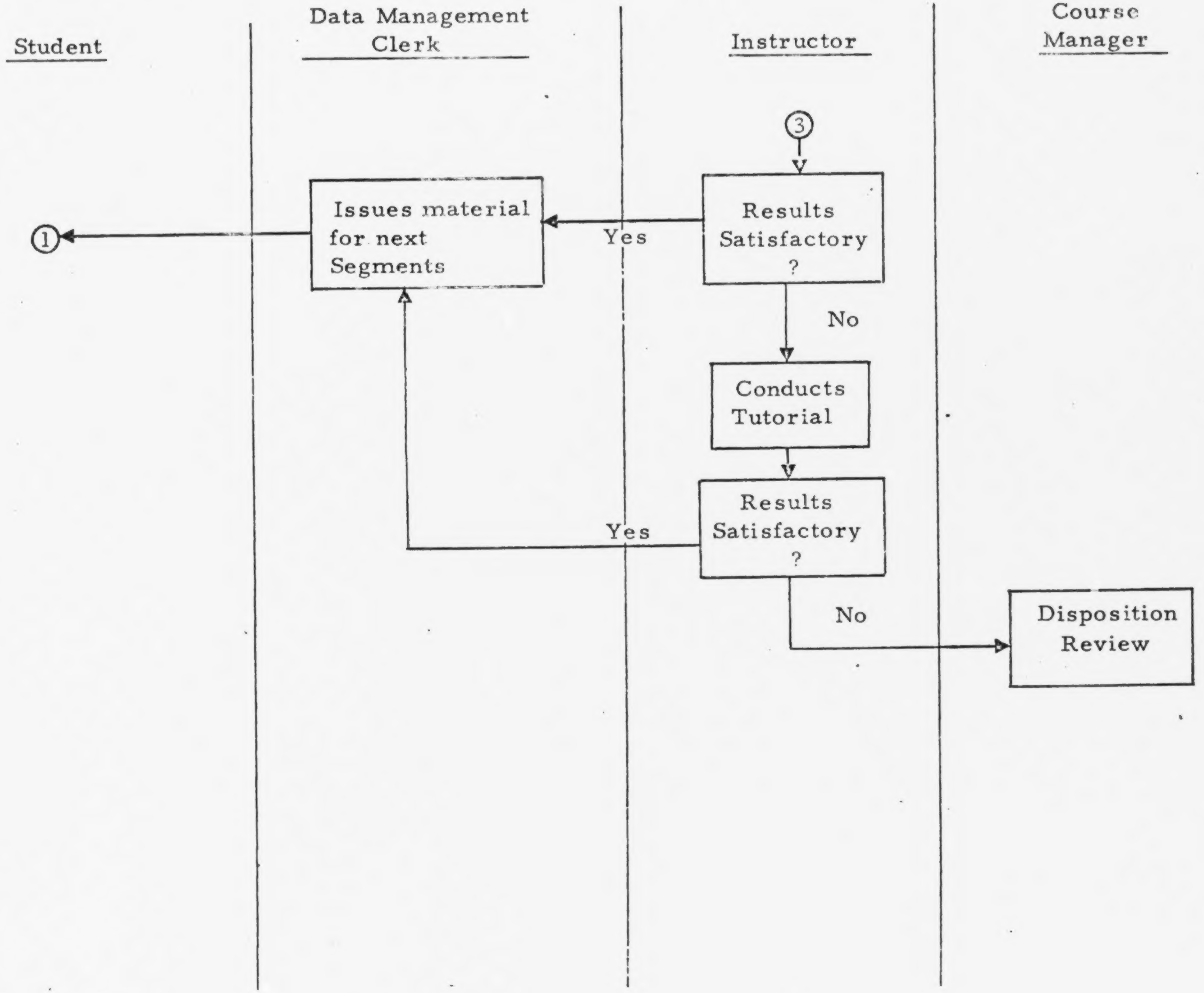

Student
Data Management Clerk
Instructor
Course Manager
Problems & Solutions
Course Policy
Student Manual
Issues complete set of materials per student
Conducts orientation & arranges issuance of material
includes -
1. Special Pen
2. Study Guide Sheets with assignments
①
Proceeds with Assignment
Assignment References A/V ?
Yes
Selects Audio/ Visual Media; student reviews appropriate T.O.'s
No
Requires Instructor's Assistance ?
Yes
Reviews subject matter with student
No
②

SELF-PACED PHYSICS COURSE (Page 2 of three pages)
(Cont'd)


Student
Data Management Clerk
Instructor
Course Manager
2
Completes Assignment
Schedules and Administers Progress Check
Results Satisfactory?
Yes
No
Issues material for next Segments
Repeats Study Sequence
1
Prepares P.C. Report
Issues remedial material assignments and/or conducts tutorial
Reviews Report for Group Remedial Strategy
Reviews Material
Requires A/V Material ?
Yes
Selects A/V Media
No
Completes Remedial Material
Schedules and Administers Retake P.C.
3

SELF-PACED PHYSICS COURSE (Page 3 of three pages)

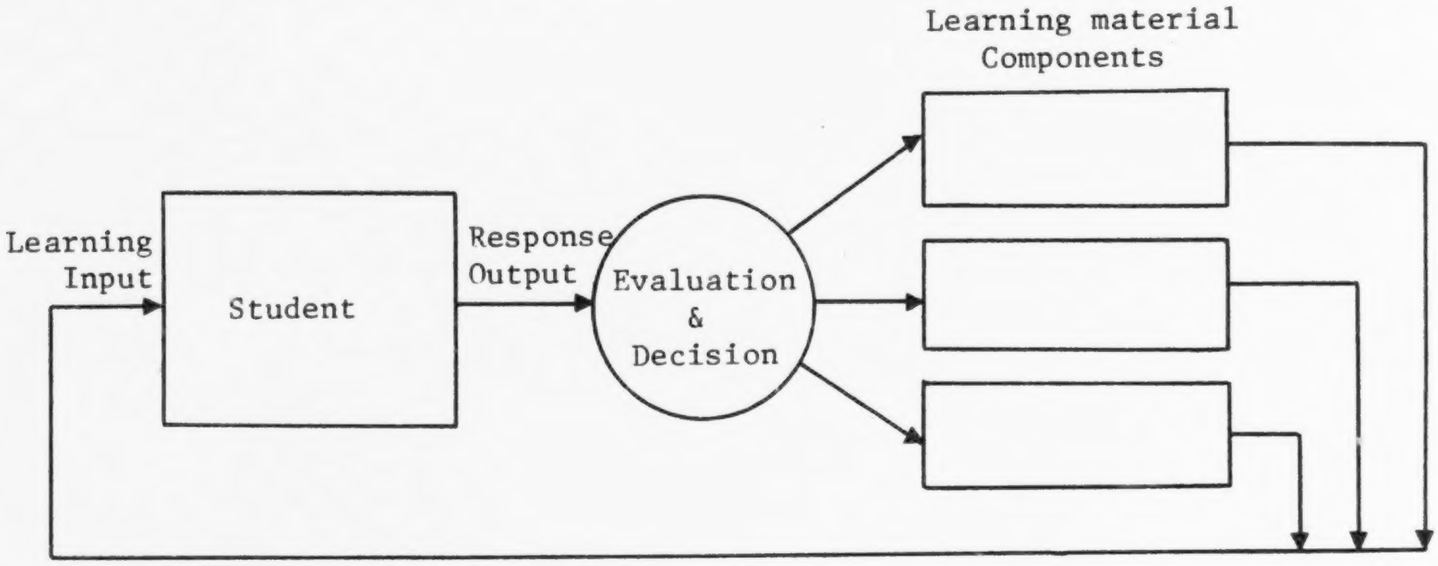
(Cont'd)


Student
Data Management Clerk
Instructor
Course Manager
3
Results Satisfactory ?
Yes
No
Issues material for next Segments
1
Conducts Tutorial
Results Satisfactory ?
Yes
No
Disposition Review

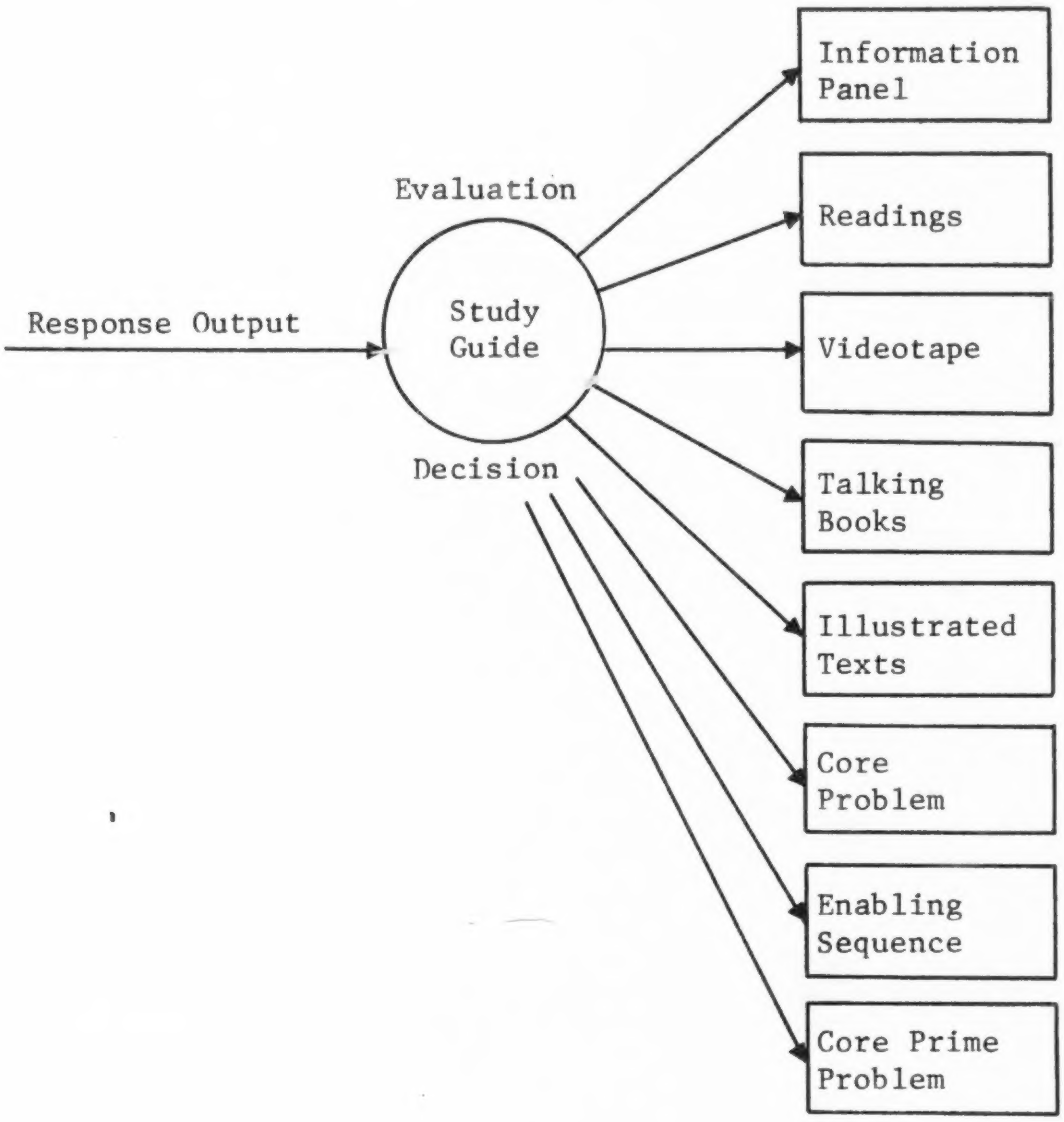
INTERNAL MANAGEMENT

Internal management, the guiding of each student through each unit of course material, is provided by several components of the instructional system. Study Guides, Progress Checks, and administrating instructors are all part of this process of directing the student through the instructional materials.

A management system should be dynamic and responsive. The system should evaluate a student's response immediately, and modify the learning input accordingly, as depicted in the feedback loop below. The diagram shows exposure to learning material as input to the student, who then gives a response as output. The response is evaluated and the student is directed to the most appropriate learning component which modifies the input and completes the loop. The physics program has two levels of internal management which are described by this feedback loop. These provide management through both formative and summative evaluation.



The Study Guide is the primary agent of individual management in the present program; it is the instrument of formative evaluation and decision making. The Study Guide reveals the correct answers; students compare their responses with those presented. On the basis of his evaluation, the student decides on various options offered by the Study Guide. These options include Information Panels, readings, videotapes, talking books, illustrated texts, core problems, enabling problem sequences, and core prime problems. This management level is illustrated in the diagram below which is a specific case of the basic feedback loop.

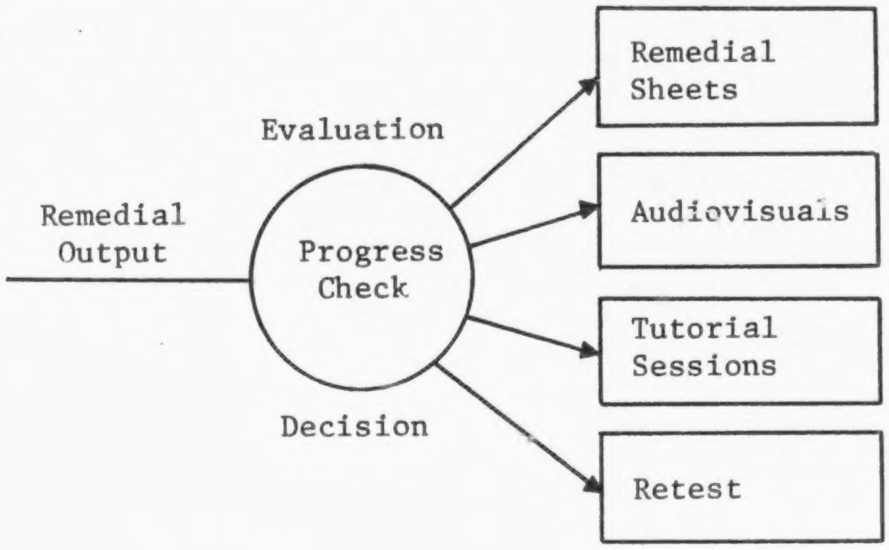

Information Panel
Evaluation
Readings
Response Output
Study Guide
Videotape
Decision
Talking Books
Illustrated Texts
Core Problem
Enabling Sequence
Core Prime Problem

Management of this kind is aimed at individualization of learning for each student according to his individual requirements. In effect, it provides a control and guide for independent study through branching programmed instruction, texts, and a variety of audiovisual support materials. The student's activities are directed in accordance with his performance, at an item by item level.

One of the goals set forth at the inception of the program was to establish optimal individualization with respect to media. The evaluation team sought to determine what media were most efficacious for a student with a known set of background variables. The disappointing result was that in the operating course they were unable to detect significant differences in performance due to media usage (see the section on Audiovisual Components). However, it is clear that media *preferences* exist, and this has become the basis of the present system of voluntary selection of audiovisual material.

Progress Checks provide the best objective evidence of a student's achievement. These are the summative evaluation instruments for internal management, providing remedial instruction or sources of corrective information after the need is identified. Administrating instructors use the Progress Checks as a basis for directing the student to various options. These options include remedial sheets with references to specific programmed instruction, audiovisual components, individual tutorial sessions, and retests on equivalent Progress Checks. The diagram of this management level is shown on the next page.

More general management considerations are discussed in the Management System Report, TR 5.4a.


Remedial Output
Evaluation
Progress Check
Decision
Remedial Sheets
Audiovisuals
Tutorial Sessions
Retest

POLICING DEVICES

The open format we recommend for Problem and Solution Books does not include the policing devices requested by the Academy staff.

Security measures were incorporated into the system to insure that all students worked through all of the instructional material.

We believe that such strictured design is an impediment to the self-paced and self-managed concept. True-false "policing" questions, scrambled text format, and hidden answer monitoring devices are all wasteful of students' time. We believe these also to be motivation dampeners.

Moreover, a great deal of effort and expenditure of time and money was devoted to the conception and construction of such security measures--all, we feel, are without justifiable purpose.

CONSTRAINTS

The development and implementation of any automated learning system will have to satisfy various constraints imposed by the nature of the institution, the nature of the subject matter, physical facilities, funds, available time, contractual arrangements, and the character and qualifications of the personnel associated with the project.

It is a virtual certainty that any other self-paced program will encounter different constraints from those met in the physics program, and will require different accommodations from the course developers.

Most of the constraints on the physics project have been described in various sections of this report. It may be useful, however, to list these constraints so that other course developers can see where they have greater latitude and where they are more strictured.

Since the self-paced course had to cover the same objectives as the conventional S211 course at the Academy, the subject matter was rather rigidly prescribed.

It was not desirable to allow Academy students to be penalized academically due to any deficiencies in the developing project. The Admiral ordered that midshipmen could not be deprived of any existing materials during the experimental phase. Thus, the textbook and additional individual instruction (tutoring) were available to the experimental group. This lack of controlled conditions precluded precise experimentation.

Academy policy required that grades be established on a norm-referenced basis. Since the program was developed on a criterion-referenced basis, this policy reduced the relevance of a major course component--the Progress Checks.

Accurate reporting procedures on the part of the students was not enforced. It is worth noting that Academy professors were much more concerned with their students' progress than with recording their progress--an attitude which was fostered by a separation of contractor and "customer."

Class size at the Naval Academy is limited to twenty students per section. It was therefore not possible to show that more students can be served by one instructor through the use of the program.

The final exams were designed by the Academy faculty including instructors of conventional sections. Two consequences of this arrangement are that course objectives are only sampled, and the test favors the sections which cover the least material (see Course Evaluation for particulars).

REVISION

The revision procedure is central to program development. By a continual process of successive revisions, the course evolves into a progressively more effective instrument. Each operation of the course produces data for the next iteration in an empirical approach to optimization.

Major revision steps in the physics project have already been described for each course component. Generally, these entailed rather drastic reconstructions of materials and working philosophies to produce the current version. Such revisions do not have a systematic character--they are often inspired answers to unexpected problems. Now that a prototype has been developed, further revisions should entail relatively small perturbations in content and materials.

Physics course designers treated these less extreme revisions with a basic methodology: every objective for which performance is unacceptable undergoes a refinement procedure whereby smaller steps toward the objective are provided together with additional learning materials and alternative paths.

The first step of the procedure is to compile all available performance measures according to the associated terminal objectives. These include: test items from progress checks, the final exam, items from the Problem and Solution Books, the associated learning categories (zero-, one-, and multiple-step), the averages on each item, the averages of the upper and lower halves of the student population on each item, and indicators to show when an audiovisual or information panel is directly associated with that objective. A page from the Data Compilation index and the key to column headings for the 1969 tryout is included as an illustration.

Validation of all items is the second step in the revision process. Each item is examined in the light of the performance data with special attention to those with the poorest performance. No arbitrary performance standards should be predetermined during this procedure because even very poor problem statements may be correctly solved by a majority of students. The converse situation of a good problem with a poor performance is even more prevalent. The reader is referred to the Test Items section for an extensive discussion regarding valid problem construction. Appropriate adjustments in the items may be made at this stage, including minor changes in sequence. A Sample Validation Page from the Revision Process Report is incorporated in this section. Notations should be made on the Data Compilation Sheets of items altered in the validation process.

The third step in revision is to compile several lists which serve to identify those terminal objectives with poor performance. The percentages used to define these lists are arbitrary--they should be raised progressively as the course evolves: In list A, include objectives on which less than 70% of the students were correct on progress check and final exam. In list B, include objectives on which less than 70% were correct on progress checks and more than 70% were correct on the final. List C includes objectives which seem to require more review, having less than 70% of students correct on the final and more than 70% correct on progress checks.

Finally, the listed objectives and the associated data are examined and various "actions" are taken which may include an increase in any or all of the following: core level problems and solutions, enabling problems

KEY TO SAMPLE

OBJECTIVES INDEX AND DATA COMPILATION

Explanation of Column Headings

PRETEST	--	Item	Problem identified by volume letter and number
		C(U/L)	Average percentage correct (In this column U/L does not apply)
POSTTEST	--	Item	Problem identified by volume letter and number
		L.C.	Learning Category
		C(U/L)	Average percentage correct (upper half/lower half)
FINAL	--	Item	Problem number
		M/F	Multiple choice/Fill-in
		C(U/L)	Average percentage correct (upper half/lower half)
STUDY GUIDE	--	Item	Problem identified by volume letter, grouping, and number
		One Punch	Number of students selecting one answer to the item
		Two, Three, and Four Punch	Number of students selecting two, three, or four answers to the item
		E.O.	Enabling objective for item
(AV)	--		The notation "(AV)" in the Terminal Objective column indicates that audio-visuals are associated with that objective

SAMPLE
DATA COMPILATION BY TERMINAL OBJECTIVE

T.O.	PRETEST		POSTTEST			FINAL			STUDY GUIDE					
	ITEM	C(U/L)	ITEM	L.C.	C(U/L)	ITEM	M/F	C(U/L)	ITEM	ONE PUNCH	TWO PUNCH	THREE PUNCH	FOUR PUNCH	E.O.
14	B2	42	B2	2	94(98/90)	9	F	96(98/94)	B1-5	121	8	0	0	01
(AV)			H4	2	98(99/98)				B1-6	122	6	0	1	02
									B1-13	53	26	34	15	00
									B2-1	57	19	16	29	03
									B2-2	73	39	6	3	04
									B2-3	38	37	33	12	05
									B2-9	60	37	16	4	06
									B2-10	58	36	13	7	07
									B2-11	80	24	6	2	08
									B2-15	65	30	14	0	09
									B2-16	51	40	15	3	10
									B2-17	25	37	39	8	11
									B2-18	88	19	0	2	12
									B2-22	42	25	20	10	13
									B2-23	35	36	20	4	14
									B3-19	31	15	10	7	02
									C3-21	8	1	0	0	00
									M1-12	40	14	6	4	00
									M3-12	13	3	4	2	00
									M3-15	8	5	6	2	00
15	B3	3	B3	3	54(74/34)	12	M	72(84/59)	B1-7	106	10	1	0	01
									B1-8	58	38	20	2	02
									B1-9	60	37	16	4	00
									B1-12	88	10	10	2	03
16	B5	8	B5	2	30(46/13)	10	F	60(72/47)	B1-20	102	21	1	2	01
									B1-21	53	58	15	0	00
									B1-22	62	50	11	2	03
									B1-23	115	5	2	3	04
									D1-8	79	22	20	1	00

SAMPLE VALIDATION PAGE

Segment 4 #14

R1	R2	R3	R4
54	47	21	6

The problem is valid and well described.

Two trivial changes to "clean-up" the solution may be made. That is, replace θ with its equivalent of 30°; and eliminate the words ". . .makes life easier and. . ."

TO 13

Segment 4 #19

R1	R2	R3	R4
37	51	35	3

This is a satisfactory item as it stands. It would, however, be in a better sequence if it was preceded by the supplementary note on tension and by problem #11, and then followed by problem #18.

TO 13

Segment 4 #21

R1	R2	R3	R4
53	58	15	0

This item is valid, however the statement of the problem is incomplete; i.e., it relies heavily on the diagram, and in doing so it may become ambiguous.

Alternate answer C may be considered invalid.

It is recommended that the statement of the problem be rephrased and alternate answer C be replaced.

TO 16

Segment 4 #22

R1	R2	R3	R4
62	50	11	2

Alternate choice "C" of this item is confusing and ambiguous. The item becomes wholly satisfactory when choice "C" is replaced by "none of the above".

TO 16

and solutions, information panels, test assignments, time available for study (provided by eliminating less important material), audiovisual materials, and alternate study guide branches. Some of these actions are depicted on an illustrative Sample Revision Action Summary. Once the revisions are made, many items will be incorporated, removed, or rearranged. Thus, some record must be kept to relate the old items to the new as is shown in the Sample Item Location Sheet.

For information panels and audiovisual materials, performance data are not sufficient criteria for revision (see Course Evaluation report). Presumably, the information content of these materials does not change during revision, but changes in format, wording, and presentation should be made. Factors such as interest, appeal, and ease of reading or viewing must be considered. These points are elaborated in the sections on Information Panels and Audiovisual Materials, and in the Revision Process Report, TR 5.5.

SAMPLE REVISION ACTION SUMMARY

POST TEST C

KEY:
IP = Information panel (number after IP = question number which follows)

CL = Core level problem
EL = Enabling level problem
PR = Problem revision
TE = Time expansion
TEX = Critical time expansion

T.O.	LIST	SEGMENT	ACTION
21	A	7	IP 1, 5, 8, 11 / CL 9, 14 / TE / PR 9, 10
22	C	7	CL 14 / TEX
23	B	7	IP 15, 18 / CL 17 / TE / PR 14, 16, 18, 19
25	C	7	IP 24 / CL 23, 29 / TE / PR 4*(8), 18*(8) * Seg 8
26	B	8	IP 9 / CL 12 / TE / PR 5, 6, 7, 8, 9
27	C	8	IP 5 / CL 8 / TE / PR 11, 12, 15, 16
29	B	9	IP 6 / CL 10 / EL 8 / TE / PR 11, 12, 13, 14, 15

FINAL: 7/6/70 (FP)

SAMPLE

United States Naval Academy
Item Location Sheet

Multimedia Physics
VOLUME ___ Segment 5

	New No.	Old No. CORE	Old No. PHYS	Col. Loc.	Information Panels and/or AUDIO-VISUALS
					IP NEWTON'S LAWS OF MOTION COMBINED
MC	1	1		18a	
COMP	2	3		14a	
MC	3		2	15b	
COMP	4		new	21a	IP COEFFICIENTS OF FRICTION
C (3 boxes)	5	8		20a	
MC	6		5	13a	
TF	7		7	17b	
COMP	8		14	22a	
c (3 boxes)	9		new	23a	IP FRICTION ON AN INCLINED PLANE
COMP	10	9		19a	
COMP	11	20		16a	
TF	12	21		15a	AV ATWOOD'S MACHINE
MC	13	10		24a	
MC	14		15	21b	
MC	15		16	13c	
MC	16		25	17a	
MC	17		new	25a	
COMP	18	11		25b	
COMP	19		12	13b	
COMP	20		13	24b	
COMP	21		new	18b	
	22	SEG 6			
	23				
	24				